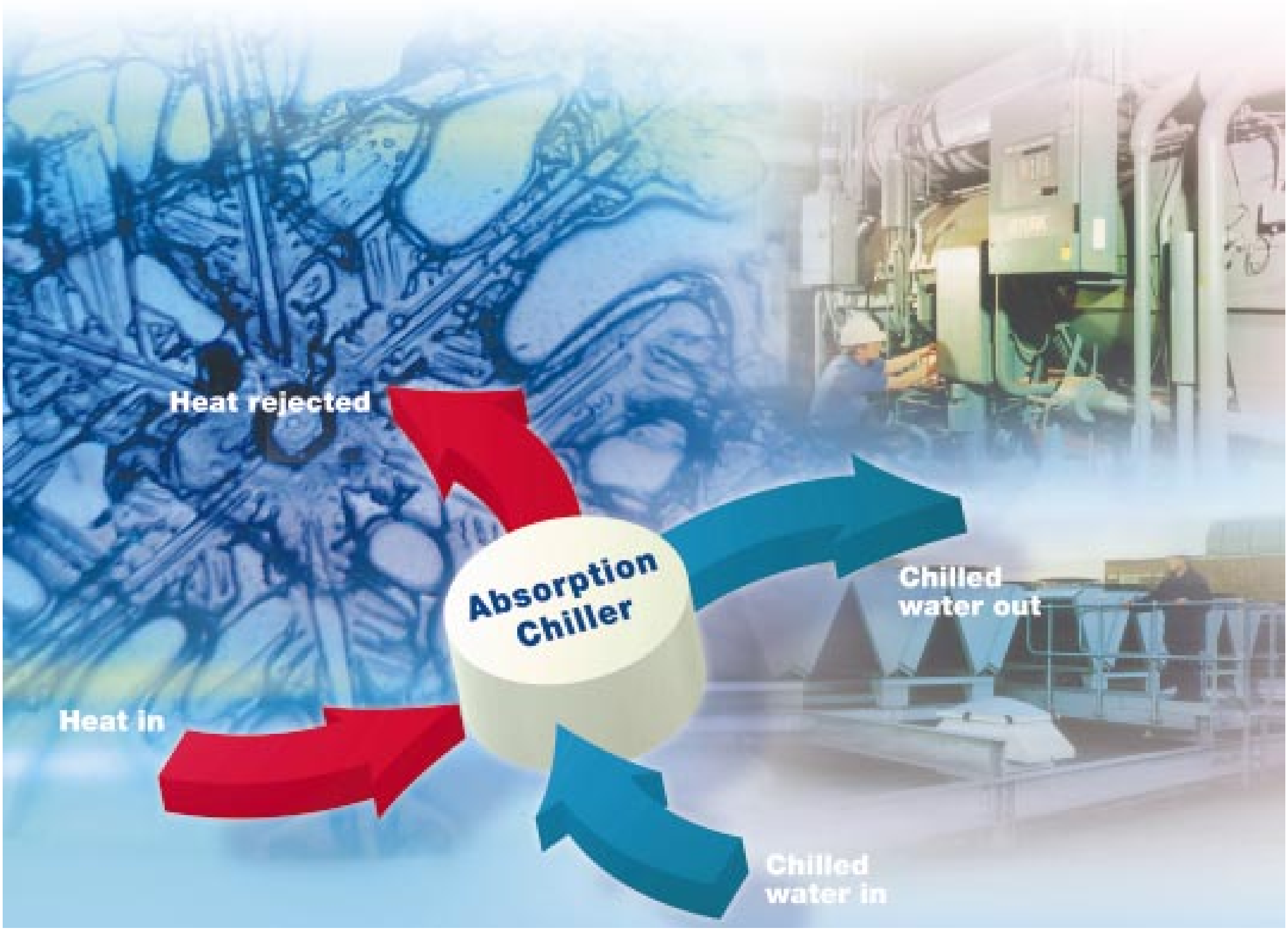
GOOD PRACTICE GUIDE 256

An introduction to absorption cooling



GOOD PRACTICE GUIDE 256

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

AN INTRODUCTION TO ABSORPTION COOLING

Absorption cooling can save money and reduce the environmental impact of your cooling plant. Improvements in the technology make it a practical and economic option for cooling systems in the right circumstances. This guide is intended to help you identify if it is the right technology for you, and show you how to move on from there.

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Other relevant titles in the Good Practice Guide series

3. INTRODUCTION TO SMALL-SCALE CHP
43. INTRODUCTION TO LARGE-SCALE CHP
69. INVESTMENT APPRAISAL FOR INDUSTRIAL ENERGY EFFICIENCY
220. FINANCING LARGE-SCALE CHP FOR INDUSTRY AND COMMERCE
226. THE OPERATION AND MAINTENANCE OF SMALL-SCALE CHP
227. HOW TO APPRAISE CHP. A SIMPLE INVESTMENT APPRAISAL METHODOLOGY
236. REFRIGERATION EFFICIENCY INVESTMENT. PUTTING TOGETHER A PERSUASIVE CASE

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FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

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If you would like any further information on this document, or on the Energy Efficiency Best Practice Programme, please contact the Environment and Energy Helpline on 0800 585794. Alternatively, you may contact your local service deliverer – see contact details below.

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CONTENTS

The Guide is structured to be as easy to use as possible, providing an introductory understanding, in the 'Essential' sections, but also satisfying those who wish to understand the more technical detail – the 'Advanced' sections. The reader may pass over the Advanced sections without losing the thread of the discussion. The following will help you find the parts that are most useful for you.

1

INTRODUCTION

The purpose of this Guide is to inform potential users of absorption cooling about the benefits and limitations of this technology. It will help readers to answer the questions “Is this technology useful for me?” and “What else do I need to know?”

The Guide is intended to provide practical advice to enable readers to be confident in asking the right questions of equipment suppliers and installers before proceeding, if appropriate, to invest in an efficient system.

To make the Guide as easy as possible to use, technical sections have been separated into boxes with an icon at the top like those shown opposite. You can miss these out, if you wish, and return to them if you need more detail.


Technical detail

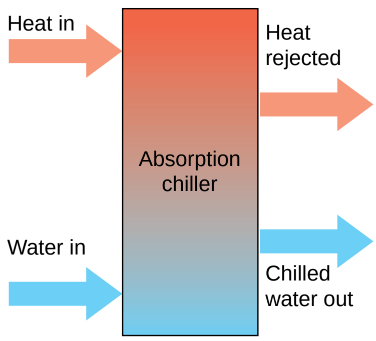

Sample calculation

Expected Readership

The Guide is written for equipment buyers, works engineers, building and site services managers, consultants and technicians. It assumes little prior knowledge of the technology. Some engineering background will be useful to readers, but should not be essential.

What is Absorption Cooling?

Simply put, absorption cooling is a technology that allows cooling to be produced from heat, rather than from electricity. The details are explained later in this Guide.



Why Haven’t I Seen One?

You probably have. Gas refrigerators were quite common in the 1950s and 1960s, and are still used in hotels, boats and caravans. These work on the absorption cooling principle described in this Guide.

There are more than 2,700 commercial and industrial absorption chillers in the UK. Most of these are relatively small, gas fired air conditioning units, but there are over 200 commercial sized ones - including more than 20 in industrial process applications.

World-wide, there are many thousands of users. The world market for lithium bromide chillers over 300 kW is around 12,000 units/year, mostly in Japan, China, Korea, USA and Germany. However, in the UK, only around 15 large absorption chillers are sold each year.

Chillers

Throughout the Guide, we refer to absorption units as chillers. We do so because the vast majority of units operate above 5°C. Some special units can operate below 5°C, and the term would not strictly apply to these.

2

WHY USE ABSORPTION COOLING?

Conventional, mechanical compression refrigeration is used in many different ways and is well proven, with a good support network of suppliers and maintenance companies. It is unlikely that absorption cooling will replace conventional systems on a large-scale, but there are many applications where it can offer an environmentally and economically superior alternative.

As a rule, absorption cooling is worth considering if cooling is required at your site, and if one of the following factors apply:

- you have a CHP unit and cannot use all of the available heat, or if you are considering a new CHP plant;
- waste heat is available;
- a low cost source of fuel is available (e.g. landfill gas);
- your boiler efficiency is low due to a poor load factor (particularly in summer);
- your site has an electrical load limit that will be expensive to up-grade;
- your site is particularly sensitive to noise or vibration;
- your site needs more cooling, but has an electrical load limitation that is expensive to overcome, and you have an adequate supply of heat.

This list provides a quick check for you to see if absorption cooling is appropriate for your site. If none of these factors apply to you, absorption cooling is probably not applicable to your circumstances.

In short, absorption cooling will find its application when a source of free or low cost heat is available, and/or if there are objections to the use of conventional refrigeration. Essentially, the low cost heat source will displace the use of higher cost electricity in a conventional chiller.

Environmental Effects

Most potential applications occur in a situation in which absorption cooling will be less environmentally damaging than alternatives: generally when the source of heat would otherwise be wasted. The environmental improvements available are often used in sales literature to publicise the technology, and this sometimes results in overselling. The absence of CFCs and other potentially damaging refrigerants is not a true environmental advantage, because the environmental impact of all cooling plant is dominated by the energy consumption of the heat source (for absorption cooling) or the power station (for electrically driven chillers).

During the preparation of this Guide, six absorption chillers were studied at a number of sites, Altogether, these chillers save the emission of 1,300 tonnes of CO_2 each year, compared to conventional alternatives.

Quantifying Environmental Effects - TEWI

If you wish to compare the environmental impact of an absorption chiller with conventional refrigeration, it is reasonable to ask potential suppliers or consultants to calculate the Total Equivalent Warming Impact (TEWI) of the proposed plant. TEWI is an index of the global warming effect of operating a chiller. The method for calculating it is set out formally by the British Refrigeration Association. The result of the calculation is a simple index number, which indicates a higher global warming effect as the index number increases.

In order to calculate this, your supplier will require details of how the plant will operate: the load profiles for heat availability or cooling demand as discussed in *Sizing your absorption chiller* on page 12.

Other Benefits

There are, however, other good reasons for choosing absorption cooling.

The first of these is that the only moving parts in a packaged absorption chiller are small internal pumps. This means that absorption units operate with much less noise and vibration than the conventional alternatives. This has definite benefits in some types of building and other sensitive areas.

Secondly, the pumps consume much less power than the compressor of a mechanical vapour compression chiller of a refrigeration unit. Where a limitation of power supply to a site exists and is expensive to overcome, absorption cooling offers an alternative that can avoid upgrading the supply.

With CHP

Applications associated with CHP can be particularly attractive, because the absorption cooling represents an additional consumer of heat, which improves the utilisation of an existing CHP plant or can improve the viability of a proposed CHP plant. These applications are described in more detail in Section 4.

The Freeman Hospital, Newcastle-upon-Tyne, has large industrial engine driven CHP. The lower temperature engine jacket heat is used for space heating, and higher temperature exhaust heat drives two absorption chillers.

Availability

There are several types of absorption chiller, and their availability varies. To explain further, it is necessary to define two basic types of absorption cooling (details of how the different systems work are explained over the page):

- lithium bromide/water systems;
- ammonia/water systems.

Lithium bromide/water systems are widely available as packaged units from several suppliers in the UK, at sizes ranging from 100 kW to 1,000’s of kW of cooling capacity. Over 200 of these are presently installed and working in the UK, and the technology can be regarded as well proven. Real experience from working plants is presented throughout this Guide.

Small (30 - 100 kW) direct-fired ammonia/water systems are readily available in the UK, more than 2,500 are in operation. Standard ammonia/water packages are available at sizes from 100 - 800 kW of cooling, with larger units available as special designs.

TECHNOLOGY BASICS

How an absorption chiller works

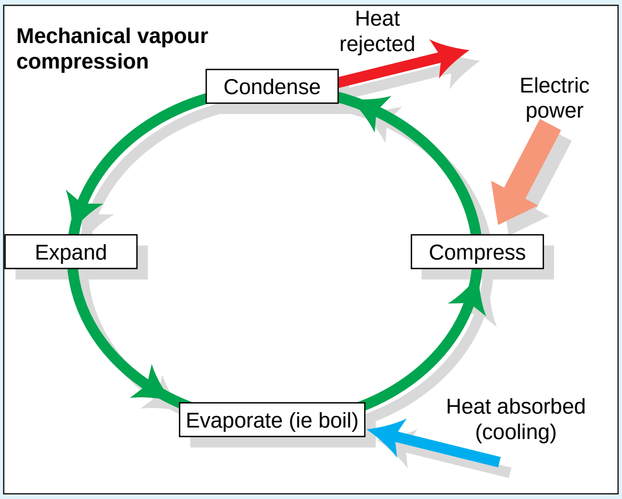
Most refrigeration plants operate on the basis of two well-known physical phenomena:

- when a liquid evaporates (or boils), it absorbs heat, and when it condenses it gives up that heat
- any liquid will boil (and condense) at a low temperature at one pressure, and at a higher temperature at a higher pressure.

A refrigerant is simply a liquid where the pressures at which boiling and condensing occurs are in the normal engineering ranges.

In the conventional, mechanical vapour compression cycle, the refrigerant evaporates at a low pressure, producing cooling. It is then compressed in a mechanical compressor to a higher pressure, where it condenses.

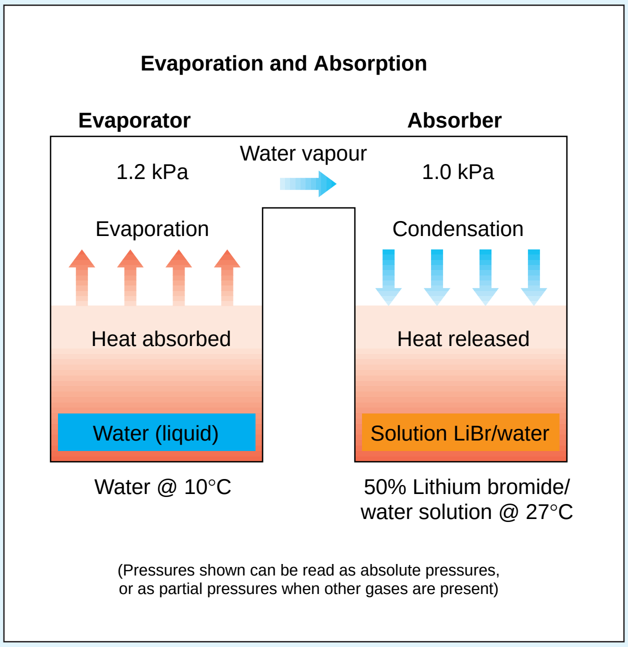
In a mechanical vapour compression unit, a compressor, normally powered by an electric motor does the compression work.



In absorption cooling, the evaporator and condenser are essentially the same, but a chemical absorber and generator replace the compressor, with a pump to provide the pressure change. As a pump requires much less power than a compressor, electrical power consumption is much lower - the heat source provides most of the energy.

Absorption cooling works because some pairs of chemicals have a strong affinity to dissolve in one another. For example, a strong solution of lithium bromide in water will draw water vapour from its surroundings to dilute the solution.

This affinity is used in absorption cooling, to draw water (which is the refrigerant) from a conventional evaporator into the absorber. From there, the weakened solution is pumped to a higher pressure, to the generator. Here, heat is applied, and the water is driven off to a conventional condenser. The re-strengthened solution can then be recycled to the absorber.



Heat is rejected from the absorber (it gets hot as it absorbs the refrigerant), and from the normal condenser.

Lithium bromide (in solution) and water are one pair of chemicals used in absorption cooling. The other well-proven pair is ammonia and water. In this case, ammonia is the refrigerant, and water is the absorbing liquid

The COP and performance of absorption chillers

For all cooling systems, it is useful to understand the concept of COP - this is referred to several times later in this Guide. It is defined as the cooling effect produced, divided by the energy input to the system (both in the same units - kW or Btu/h, etc.).

When comparing COPs for different systems, it is wise to include all of the energy consumers, not just that applied to the chiller itself.

The COP of an absorption chiller is typically about 80% of the ideal COP (derived theoretically). The ideal COP of a single effect chiller is defined by either of two pairs of variables, which give a useful insight into the factors that affect a chiller's performance:

$$\text{Ideal COP} = \frac{T_e}{T_a} \quad \text{and} = \frac{T_c}{T_g}$$

Where all temperatures are in Kelvin (K), and:

T_e is the temperature inside the evaporator, controlled by the temperature of the chilled water produced.

T_a is the temperature inside the absorber, controlled by the cooling water outlet temperature.

T_c is the temperature of the condenser, also controlled by the cooling water outlet temperature.

T_g is the temperature inside the generator, controlled by the outlet temperature of the heat source.

TECHNOLOGY BASICS *(continued)*

These relationships show how the relative temperatures of the heat source, chilled water and cooling water affect performance. Generally, increasing either of the two ratios will give increased output:

- a higher chilled water temperature (T_e) gives a higher COP and cooling capacity;
- a lower cooling water temperature (T_a) gives a higher COP and cooling capacity;
- a higher temperature heat source (T_g) gives a similar COP, but increases cooling capacity.

In each case, it is the outlet temperature that has the largest effect.

Absorption in practice

The diagram below shows how the absorber, pump and generator are arranged in a single effect (defined below) lithium bromide/water absorption chiller.

The refrigerant vapour in the evaporator is absorbed in the absorber, and the mixture is pumped to the generator. In the generator, heat is applied, and the refrigerant is boiled off to a conventional condenser. The absorbing liquid is returned to the absorber. In a packaged lithium bromide/water absorption chiller, all of the items shown, except the pump, will be enclosed in one or more steel shells, together with the conventional evaporator and condenser.

In the diagram, two features may be observed that have not been explained. Firstly, there is a heat exchanger between the absorber and generator. This serves to improve the efficiency of the unit. Secondly, the absorber includes a cooling heat exchanger. This is required because as the refrigerant is absorbed, heat is generated and must be removed.

The diagram shows a single effect absorption chiller. In double and triple effect units, some of the heat is recycled internally to improve efficiency, but these units require a higher temperature heat source (see *the number of effects* below).

Types of absorption plant

It is useful and common practice to divide absorption plant into categories in several different ways: by the type of heat source, by number of effects and by the chemicals used in the absorption process. Thus, a unit may be described as a hot water source, single effect, lithium bromide/water type. The terms are explained as:

Type of heat source

Heat will generally be supplied to an absorption unit as hot water, steam or directly by burning natural gas. Other sources, such as hot gases, are theoretically possible, but require a special design, rather than the application of one of the off-the-shelf designs.

The number of effects

As explained above, it is possible to purchase single and double effect plants. Triple effect plants are under development. Double effect plants are more efficient than single effect, but also cost more.

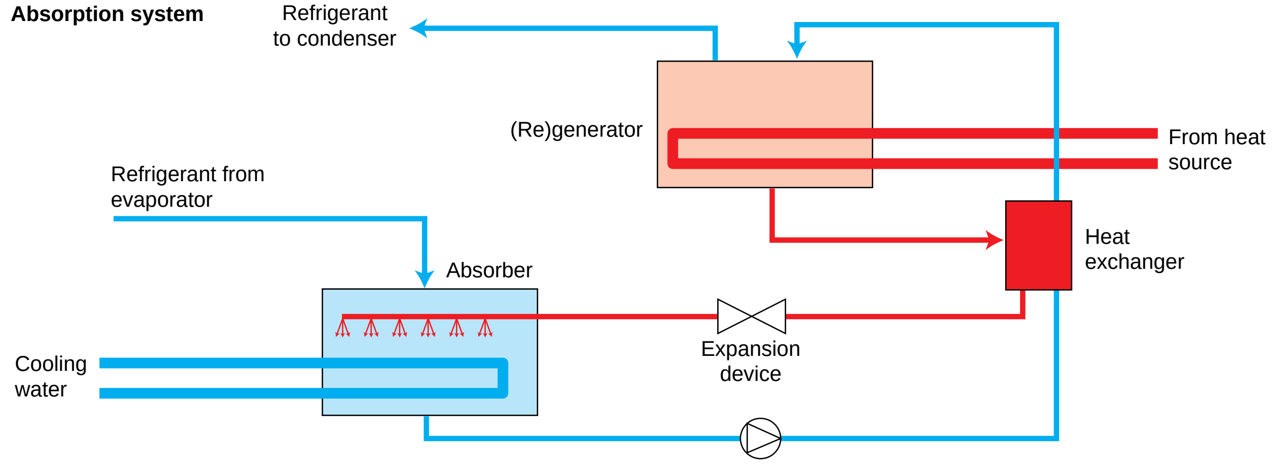
The determining factor is the temperature at which heat is available, with double effect units typically requiring heat at 140°C or above. This is normally available only from natural gas fired directly into the absorption unit, from steam at 7 - 9 barg or from pressurised hot water at around 160°C.

The chemicals used in the absorption process

An absorption unit needs two chemicals with a strong mutual attraction in order to operate. Although other pairs are possible, lithium bromide/water and ammonia/water are the two pairs commercially proven. In lithium bromide/water types, water is the refrigerant and is absorbed by a strong solution of lithium bromide. In ammonia/water types, ammonia is the refrigerant and is absorbed by water.

In lithium bromide/water units, the water refrigerant (which freezes at 0°C) is the reason that temperatures below about 5°C cannot be achieved.

Absorption system



3

IS ABSORPTION COOLING SUITABLE FOR YOU?

The previous Section highlights those applications where absorption cooling may well be a good choice. However, many potential obstacles, real and fictitious require consideration. These, and choosing an appropriate form of absorption cooling, are described below.

Choosing the Appropriate Technology

This process is best described diagrammatically as shown opposite.

Temperature Limitation

Lithium bromide/water units suffer from one major limitation: the chilled water temperature that they can produce. For most practical purposes, this is limited to about 5°C. This limitation is caused by the use of water as refrigerant and cannot be solved by adding an anti-freeze agent to the chilled water, as for conventional chillers.

The ammonia/water absorption chiller at Van den Bergh's factory in Holland produces cooling at -23°C.

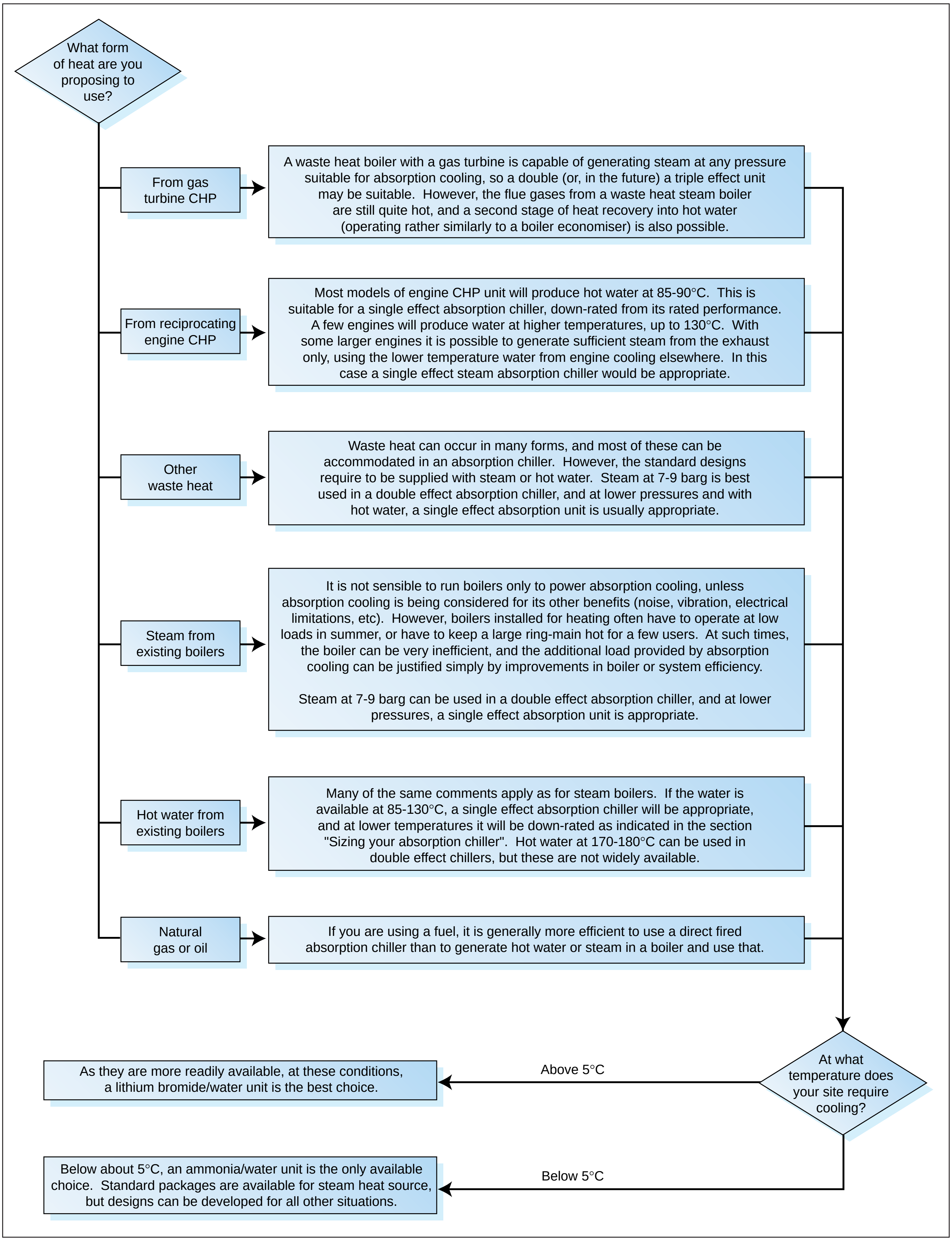
Photo courtesy of Stork Thermeq BV

Ammonia/water units are not subject to this limitation, although larger units and especially low temperatures require custom designs. With the exception of small, direct gas-fired units, none are presently installed in the UK, although the companies that offer this equipment have wide experience of the technology.

The principle advantage of ammonia/water systems is that the limitation on cooling temperature is removed, and temperatures as low as -60°C are possible. The cost premium for the limited range of ammonia/water packaged units is small, but custom-built units are inevitably more expensive.

Which Absorption System for which Heat Source?

This figure helps you to examine the right type of absorption system, based on the heat source(s) that you have available.



Heat Rejection

All cooling systems effectively take heat from one place (the item being cooled) and reject it elsewhere, usually to atmosphere by way of cooling towers or dry air coolers. Absorption cooling is no exception, but absorption units reject more heat than conventional alternatives.

This means that the cooling towers or dry air coolers will be larger, with corresponding extra cost (especially if the absorption chiller is replacing an existing, conventional plant). Details of the heat rejection for different types of absorption chiller are shown over the page.

Among the sites visited during the preparation of this Guide were three hospitals. Of these, one, the Royal Free Hospital (London) used cooling towers for heat rejection. The remaining two used dry-air coolers, because of the hospital policy not to use cooling towers. All reported reliable operation.

Heat Rejection Temperature

A limitation, applicable to lithium bromide chillers, is the temperature at which heat is rejected from the system. At the temperatures that occur in conventional dry air coolers in the hottest summer weather, the cooling output of an absorption chiller is downgraded even more dramatically than a conventional chiller. This is explained more fully over the page.

In UK conditions, the simplest way of avoiding this is to use a cooling tower for heat rejection.

An alternative is dry-air coolers with spray assistance. These issues are discussed more fully in Section 6.

HEAT REJECTION

Heat rejection - quantities

The quantity of heat that must be rejected by the chiller is equal to the energy input to the chiller plus the cooling duty. A low coefficient of performance results in a high rate of heat rejection. When replacing an existing water-cooled vapour compression chiller with an absorption chiller, it is important to ensure that additional condenser water capacity is provided. The table below shows a simple comparison of the quantity of heat rejection needed relative to vapour compression

Heat rejection - temperature

The temperature at which heat is rejected is especially important for absorption chillers, because the condenser water removes heat from both the condenser and the absorber - so both the cooling and condensing parts of the cycle are affected. The temperature of the condenser water leaving the chiller is more important than the temperature supplied to it. The standard temperature range used for quoting the nominal output of absorption chillers is condenser water entering at 29.4°C and leaving at 35°C, but UK weather permits lower temperatures, and these will give better COP and cooling capacity.

The cooling requirements are also affected by the temperature of the chiller's heat source, and the following simple rules have been shown to give optimised results in the UK for single effect systems:

- for condenser water to a chiller using heat supplied at 115°C, choose the condenser water flowrate to give a 7 degree C difference between inlet and outlet, and size the cooling tower to give an outlet temperature 7 degrees above the ambient wet bulb temperature;
- for condenser water to a chiller using heat supplied at 90°C, choose the condenser water flowrate to give a 5 degree C difference between inlet and outlet, and size the cooling tower to give an outlet temperature 5 degrees above the ambient wet bulb temperature.

Heat rejection per kW of chiller output (at typical chilled water conditions)

Type of chiller	Lithium bromide absorption			Mechanical vapour compression
	Single effect steam/HW	Double effect steam	Double effect gas fired	Electric reciprocating
Coefficient of performance (see definition in "How an absorption chiller works")	0.68	1.2	1.0	>4
Heat rejected to condenser water (kW), also called heat dissipation ratio = (1 + (1/COP))	2.5	1.8	1.8*	<1.3
Condenser water duty relative to vapour compression	>1.9	>1.4	>1.4	1.0

** For direct fired chillers only, heat dissipation ratio = (1 + (1* efficiency)/COP), where "efficiency" relates to heat losses in the flue gas (typically 0.8)*

Start-up, Shut-down and Load Following

Absorption chillers take up to 15 minutes for the generator to get up to working temperature when they start-up. Similarly, they take a little time to shut-down. Mechanical vapour compression chillers will start-up and shut-down in a few minutes. The response of an absorption chiller to changing loads is also generally slower. If load following is important in your application, it is worth exploring this with different suppliers.

Although load following is a potential problem for absorption chillers, non of the sites studied during the preparation of this Guide reported difficulties. Even for the process load at Van den Berghs, it was reported that the chiller could follow the load as required

In many applications, the speed of load response will not cause a problem. For example, in air conditioning, the load does not normally change rapidly, so the absorption chiller will be able to respond to changes sufficiently quickly. Large commercial or industrial chilled water or secondary refrigerant systems also have a slow rate of change. In some applications, it may be necessary to use a buffer tank to increase the inertia of the chilled water circuit.

Some manufacturers will add a variable speed drive to the solution pump in order to improve load following response and the part load COP.

Another possibility is to install a standby electrically driven chiller (if one is installed for standby or peak loads) in series with the absorption chiller. The conventional unit should be chosen to have good part-load performance, and will follow the load changes, and compensate for the absorption chiller's slower response. However, in any situation where an absorption chiller is connected in series with a conventional chiller, it is preferable for the absorption chiller to be installed upstream of the conventional chiller, thus avoiding rapid changes to the absorption unit's inlet temperature.

It is generally a good idea to avoid frequently starting and stopping absorption chillers.

Space and Access

The space required for an absorption chiller is normally similar to that required for a conventional, mechanical vapour compression machine. Access requirements are slightly less, as there is no compressor to be removed for maintenance. For both absorption and conventional plant, access is required for cleaning of heat exchangers, and replacement of heat exchanger tubes in addition to the normal 'walk around' space.

However, heat rejection systems, particularly dry air coolers, require significantly more space than conventional systems.

Three Common Misconceptions

(a) In the past, operating problems have occurred in lithium bromide/water units, when the lithium bromide has begun to come out of solution **(crystallisation)**. Improvements in control technology have made it possible to identify the conditions when this can occur, and hence to avoid it.

All manufacturers now include features in the control system of an absorption chiller to prevent crystallisation. It is advisable to ask potential suppliers to explain how their system copes with situations that might cause crystallisation, particularly prolonged power interruptions.

(b) **The Coefficient of Performance** (COP - defined in *How an absorption chiller works* on page 4) is a term used to reflect the efficiency of a cooling plant. For absorption and conventional cooling of chilled water, typical COPs are:

- for a single effect absorption chiller, about 0.68;
- for a double effect absorption chiller, between 1 and 1.3, 1.2 is typical;
- an electrically powered mechanical vapour compression unit on chilled water service can achieve a COP of 4 or more.

Considered simply, this implies that absorption chillers are much less efficient than conventional units. However, this can be misleading, firstly because absorption chillers can use low-grade heat that would otherwise be wasted.

Secondly, what is environmentally important is the total quantity of CO_2 released. The relatively low efficiency of generation and transport of electricity reduce the effective COP of electric chillers. When the absorption chiller is used in conjunction with waste heat, the net effect is lower CO_2 emissions, because the energy used would otherwise be wasted. With a CHP unit, the overall effect is to generate electricity with lower CO_2 releases than conventionally generated power.

During the preparation of this Guide, several absorption chiller installations were studied. The results support the general statement that where waste heat or CHP provides the heat source, the release of CO_2 and hence the environmental impact, is lower than for conventional, electricity driven chillers.

When considering a direct, natural gas or oil fired absorption chiller, the situation is more complex. It is necessary to compare the CO_2 released at the power stations generating electricity for equivalent conventional cooling with the CO_2 released by absorption chiller. The CO_2 volumes are the same order of magnitude, but detailed analysis will normally favour the conventional unit.

(c) **Corrosion** of copper and steel parts in an absorption chiller has been a problem in the past, because uninhibited lithium bromide solution is corrosive. The corrosive effect is not a problem if the lithium bromide solution is suitably inhibited (corrosion inhibitors are now well proven), and if the manufacturers make adequate allowances in their selection of tube material and thickness.

SIZING PLANT

Sizing your absorption chiller - factors to take into account

Load cycles and baseloads

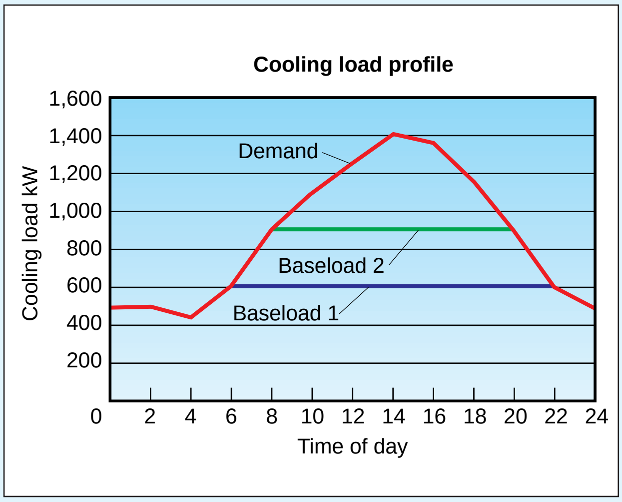
Any cooling plant has a peak load that it is required to meet at times, although for most of its life, it will operate well below this. Absorption chillers are rather more expensive to buy than conventional equivalents, and it makes sense to size for the baseload rather than the peak. The following discussion explains the concept of matching chiller capacity to cooling loads, but the same principles can be applied to supply and demand of heat and electricity.

The cooling loads at a site will generally depend upon the type of building or process concerned. For air conditioning of buildings, these loads will vary according to the time of day, the time of year, the weather conditions and the occupancy level. A number of daily load profiles may have to be assessed throughout a typical year of operation to build up a clear picture. For manufacturing processes, the situation can vary from constant demands to rapid load changes, or a combination of both: this often requires careful detailed analysis.

The baseload cooling demand is the amount of cooling that is exceeded for a large proportion of the time. This baseload requires a chiller to be operating close to its capacity for long periods. Any peaks above this baseload will require further chillers to operate, but for much shorter periods.

When considering installing a baseload unit, it is sensible to look at load profiles at different times of the year to determine the average load over time. A solution giving a high average is more likely to be cost-effective.

The selection of a base load is illustrated in the graph below.



In this example, the minimum cooling demand at night is 400 kW and the peak during the day is 1400 kW, but with little variation over the year. If an absorption chiller of 600 kW capacity is chosen, it will supply cooling as shown by Baseload 1. Over a 24-hour period, the chiller will operate at an average of 95% of its rated capacity.

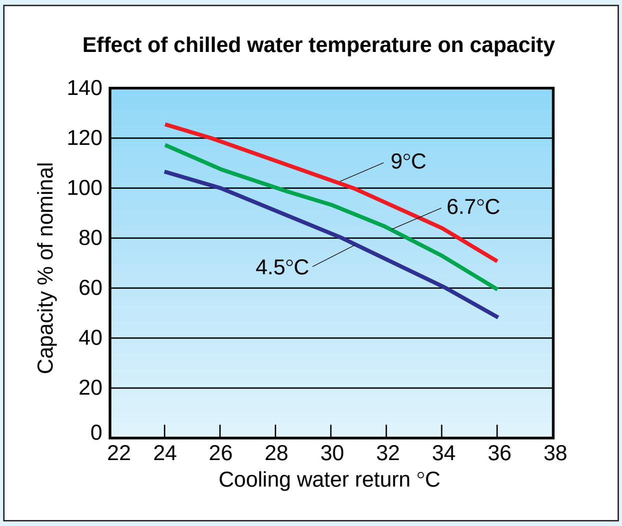
Alternatively, a larger absorption chiller of 900 kW could be installed to supply cooling as in Baseload 2. In this case, the chiller will satisfy a larger proportion of the total cooling demand but will operate at a lower average, 83% of its rated capacity.

If an electric chiller can be used on night rate electricity, the 900 kW absorption chiller would operate on Baseload 2 during the 17-hour day at 95% of its rated output.

Whenever baseload units are considered, additional chillers will be required to satisfy the remaining demand. Depending upon your main aim in considering absorption cooling, this may or may not be desirable (see Additional cooling and standby below).

Temperature of cooling output

The standard chilled water conditions for lithium bromide absorption chillers are an inlet temperature of 12.2°C and an outlet of 6.7°C. Higher outlet temperatures give an improved chiller COP.



Lower temperatures down to about 5°C flow can be achieved, but this will reduce the output and efficiency resulting in higher capital and running costs.

For example, a single effect absorption chiller might have its nominal rating specified at a condenser water return temperature of 28°C and chilled water flow temperature of 6.7°C. If the unit is operated with chilled water at about 5°C, the capacity will be reduced by 10%, or one that is 10% larger may be required.

Lower flow temperatures will increase the cost and lower the COP of the absorption chiller. At the same time, they may increase the performance and lower the costs of the cooling distribution system, they serve. It is necessary to balance these opposing effects, and this complex topic is discussed fully in a paper quoted in Appendix B.

Your heat sources

When considering absorption cooling, one objective will be to use a cheaper source of energy. Energy can be provided either directly (from gas or oil) or indirectly (as hot water or steam). Usually, the cheapest sources of energy are heat from CHP systems or recovered waste heat.

SIZING PLANT *(continued)*

Temperature of heat source

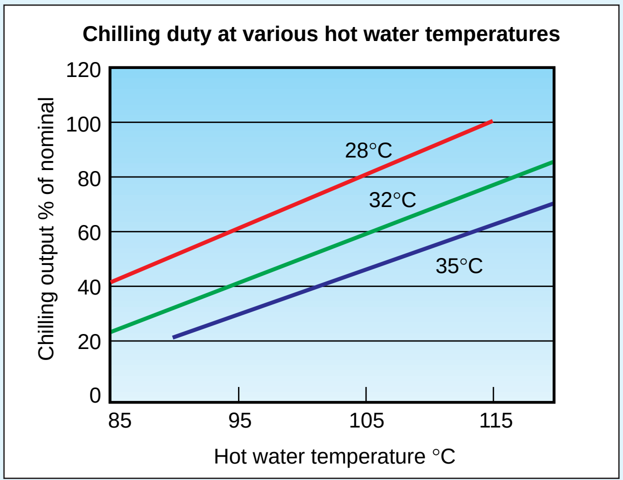
Absorption chillers usually operate with heat supplied at 85 - 170°C. It is best to obtain heat at the highest temperature possible within this range, keeping the return temperature as high as possible.

Gas and oil fired lithium bromide chillers will usually be the double effect type to take advantage of the high-grade heat available from direct combustion. Steam heated double effect chillers typically use steam at 7 - 9 bar. Single effect models use low-pressure steam or hot water between about 85 and 115°C (maximum 140°C).

For single effect units, the chiller output varies with the inlet and outlet temperatures of the heat source, but the outlet temperature mostly defines the performance. The practical minimum outlet temperature is 80°C (for single effect units), and should be as high as possible - this will maximise cooling output and allow the chiller to cope with higher condenser water temperatures.

The manufacturers market the units with a nominal cooling duty, specified at a particular inlet and outlet temperatures for the heat source, condenser water and chilled water streams. Using lower heat source temperature, higher condenser water temperature or lower chiller water temperature will reduce the cooling output significantly. This means a larger, more expensive machine will be required.

For example, a chiller nominally rated for hot water supplied at 115°C and leaving at 105°C and condenser water supplied at 28°C will only give 50% of the duty with hot water entering at 90°C and leaving at 80°C. Thus, a chiller of twice the nominal duty must be installed. The graph below shows some typical data for the down-rating effect of lower heat supply temperatures (assuming a 10 degree C drop in water temperature). A larger temperature drop (lower outlet temperature) also has a down-rating effect. In both cases, the down-rating effect varies from one model to another, so check with your manufacturer once you are more certain of the unit you will use.



Quantity of cooling possible

The cooling output is equal to the heat input multiplied by the COP for the chiller. For example, a single effect chiller with a COP of 0.67 can produce 1,000 kW of cooling from 1,500 kW of heat. Relevant COPs, are shown in *Heat rejection* on page 9.

Turndown

Typical absorption chillers can work down to 25% load. It may be necessary to buy more than one if the expected load range is large.

Absorption chillers also react to load changes more slowly than conventional chillers. A fuller discussion of this will be found in the main text in Section 3.

Additional cooling and standby

If an absorption chiller is sized for less than the peak cooling demand, a means of top-up cooling will be required. Most cooling installations also require standby.

Peak cooling and standby will normally be provided by conventional electrically powered systems, because:

- conventional chillers generally cost less than their absorption equivalents, so their use will be more cost-effective for limited running hours;
- costs for night rate electricity are low, and unless your heat source is very low cost, it will be cheaper to use electrical powered cooling at night.

If the electrically powered unit will operate for long periods, its efficiency will be important. Good Practice Guide 262 offers advice on how to specify plant for good efficiency.

Standby heat source

Absorption chillers that use waste heat or heat from CHP can be provided with a back-up heat source from boilers. This will ensure that cooling is available when the normal source of heat is not.

In this case, it is advisable to ensure that the back-up heating system matches the normal heat source as closely as possible. If the boiler serves other consumers, an intermediate heat exchanger may be required to ensure the correct temperatures and flows are maintained.

SIZING PLANT
(continued)

Sizing your absorption chiller - making decisions

Firstly, it is important to decide what is your main objective in purchasing an absorption chiller. Do you want to:

- Exploit an available source of waste heat?
- Purchase a larger CHP unit or increase the utilisation of an existing one?
- Satisfy all of your cooling demands?

In each of these cases, the approach is different, although the things to be considered are much the same.

A. Sizing on heat availability

Firstly, it is necessary to quantify both the availability of heat and the requirement for cooling, and the respective hot and cold circuit temperatures.

The temperature of the heat will determine whether a single or double effect unit is appropriate (see *Technology basics* on page 5).

The temperature of the required cooling will determine firstly the choice of the lithium bromide/water or ammonia/water type, and secondly the ratio of cooling output to heat input (the COP as discussed above).

It is then easy to compare the peak and baseload heat availability and cooling demands. It may be obvious which is the decisive factor:

- The cooling demand may limit the amount of heat you can use: in this case it may be best to size one or more absorption chiller(s) for the peak cooling demand (see *Turndown* above).
- The heat supply may limit the amount of cooling you produce: in this case you have two choices:

  you can size the absorption chiller to match the peak heat output, in which case the cooling delivered will vary with the heat supplied (see *Turndown* above);

  you can size the absorption chiller to match the baseload heat availability, in which case the absorption chiller will be fully utilised, but excess heat may be wasted.

In either case, additional cooling will be required (see Additional cooling and standby above).

B. Absorption cooling with CHP

If you are considering adding an absorption chiller to an existing CHP unit, the discussion is the same as for any other source of low-cost or waste heat, as above. However, optimising a proposed installation is rather more complex, and the process is described in a separate technical section *Sizing with CHP* on page 20.

C. Sizing on cooling demand

Whether to size your absorption chiller for baseload demand or for the peaks, will depend on your motive for considering absorption cooling.

If you are sizing for the peak load, consider the turndown and load following properties of absorption chillers - it may be a good idea to buy more than one (see *Turndown* above).

In many cases, it is sensible to size for a baseload, as described in *Load cycles and base loads* on page 12. Top-up and possibly standby plant will then be required as described in *Additional cooling and standby* above.

In the case used as an example in the technical section *Sizing your absorption chiller - factors to take into account* on page 12, a 900 kW absorption chiller could be chosen to operate for 17 hours/day (Baseload 2). This would operate at an average of 95% of its rated duty over the 17-hour daytime period - a reasonable utilisation factor.

SIZING EXAMPLE

Worked example - sizing an absorption chiller

For this example, we will consider the site whose baseload is shown near the top of *Sizing your absorption chiller - factors to take into account* on page 12. The graph and the accompanying discussion show that using a cooling baseload of 900 kW over 17 hours/day means the unit will operate at an average of 95% of its rated capacity.

We will assume that heat is available in the form of steam from a waste heat source at 2 bar, saturated temperature 133°C, and the chilled water flow temperature required is 7°C.

The condenser water is available from the cooling tower at 28°C.

Evaluation and calculation

- The temperature of the steam means a single effect absorption chiller is the appropriate type of chiller.
- The condenser water flow temperature means a lithium bromide absorption chiller is appropriate.
- The steam pressure needs to be reduced for most single effect absorption chillers because rated steam pressure is 1.2 bar. The temperature is high enough to ensure that the chiller will operate at 100% of its nominal cooling capacity.
- The chilled water temperature is also high enough to ensure that the chiller will operate at least at 100% of its nominal cooling capacity, and with a typical COP around 0.68.
- Therefore, as a 900 kW absorption chiller is required this chiller will require a heat input of:

  900 kW / COP
  900 kW / 0.68
  = 1,350 kW

- Assuming that the condensate from the steam will be sub-cooled by 20°C, the steam will provide:

  2,247.6 kJ/kg

- Therefore, steam required is:

  1,350 kW / 2247.6 kJ/kg
  = 0.6 kg/s steam

  If insufficient steam is available at these temperatures, the size of the absorption cooler must be reduced accordingly.

Heat rejection will be:

Cooling duty *(1 + (1 / COP))
= 900 kW *(1 + (1 / 0.68))
= 2,223 kW

From this, and the specification given in *Heat rejection - temperature* on page 9, the cooling tower manufacturer will be able to provide an appropriate quotation.

4

ABSORPTION COOLING WITH CHP

This Section explores how absorption cooling can add value to a CHP project - by increasing the utilisation of an existing plant or by improving the financial case for a proposed installation.

The Guides listed below explain the issues around CHP itself.

GPG 3 *Introduction to Small-scale CHP* (for CHP up to 1 MW of electrical output)

GPG 43 *Introduction to Large-scale CHP* (for CHP greater than 1 MW)

GPG 220 *Financing Large-scale CHP for Industry and Commerce*

GPG 226 *The Operation and Maintenance of Small-scale CHP*

GPG 227 *How to Appraise CHP - A Simple Investment Appraisal Methodology*

Potential Advantages of Absorption Cooling with CHP

CHP plants are normally sized to match the base-load heat or electricity demand of the site. To maximise the financial benefits of CHP, all the electrical and heat output of a plant must be used. The level of electrical demand, and the ratio of heat demand to electrical demand (the heat to power ratio) will determine the size of CHP unit that is appropriate for any particular site.

In most cases, it will be the heat demand that determines the CHP unit's size. The result is that most CHP units are smaller than the electrical base-load demand of the site they serve. If the site also requires cooling, absorption cooling offers two potential advantages:

- an additional heat load, allowing increased running hours;
- a reduction in electrical demand, by displacing the need for electrically powered cooling.

Thus, at the design stage, it may be possible to specify a larger CHP unit that will economically generate more electricity, and simultaneously use the extra heat to reduce the electricity demand.

Alternatively, if an existing CHP unit's output is limited by the demand for heat, an absorption chiller will increase the utilisation of the CHP plant, and its electrical output.

A logical procedure for selecting the optimum size of a new CHP plant with absorption cooling is described in *Sizing absorption cooling for a new CHP installation* on page 18.

For an Existing CHP Installation

If an existing CHP plant is under-utilised, the first step is to compare the amount of heat that could be available, (from the unit's capacity) and records of its actual output. The factors in Step 5 of *Sizing absorption cooling for a new CHP installation*, can then be used to calculate the amount of cooling that an absorption chiller would produce from the extra available heat.

The resulting cooling output can be compared with cooling demand. If the cooling produced by the absorption chiller will displace cooling from an electrically powered refrigeration plant; the electricity demand will be reduced. The CHP unit will also be able to operate at a higher average load, generating additional electricity in proportion to the increased heat output.

> A large chemical factory needed some new chillers for process cooling. The site included a gas-turbine CHP producing steam, and the site steam demand was falling. Lithium bromide/water chillers provided an extra steam demand, and avoided increased electricity consumption.

SIZING WITH CHP

Sizing absorption cooling for a new CHP installation

Optimising the size of CHP with absorption cooling requires a structured approach. The following steps present such a logical process. The conversion factors (COPs, etc) are approximate, and should be replaced with specific ones for your machines when they become available.

Step 1
Establish your site's electrical demand profile

Establish your site's electrical demand profile. Your electricity supplier should be able to provide you with the electrical demand for every half-hour in the last year. Establish the baseload demand in the same way as described above for cooling (see "Sizing your absorption chiller"), to indicate the size of CHP unit that might be applicable. Bear in mind that it is normally most economic for reciprocating engines to be switched off during the low-cost night period, but gas turbines in the right economic circumstances can operate continuously.

Step 2
Quantify your cooling demands

Quantify your cooling demands, as described in the section 'sizing your absorption chiller', above. This will give the range of absorption chiller sizes that are appropriate for your site.

Step 3
Reduce your electrical demand to allow for cooling from the absorption chiller

If your electrical demand profile includes existing electrically powered cooling plant, reduce the actual electrical demand to allow for the fact that the possible absorption chiller will replace a proportion of this electricity demand. If your cooling plant is separately metered, this is simple, otherwise it may be estimated by subtracting from your base load electricity demand the cooling demand in kW, divided by the COP of the existing cooling plant. If no better COP figures are available, you could use:

- 4, if your cooling plant is producing chilled water
- a factor between 4 and 2 if the cooling plant is producing cooling at between 0°C and –30°C.

It is necessary to add the additional power required for heat rejection fans and pumps for the absorption chiller - initial data is shown in "Calculation of financial benefits - operating costs".

Step 4
Establish the type of CHP unit that is likely to be appropriate

Establish the type of CHP unit that is likely to be appropriate:

- Gas turbines are available in many sizes, and are particularly attractive if steam is required.
- Reciprocating engines are appropriate for all sizes, provided that steam or hot water above 130°C is not required. Most engines produce hot water at about 90°C with larger ones giving up to 115°C, but special, high temperature units are also available.

Step 5
Convert your cooling demand to heat

Convert the base-load cooling demand calculated in step 2 to heat demand by dividing by the appropriate absorption COP. For a first estimate, the conversion factors shown below may be used (these figures are for lithum bromide/water units; for other conditions and for ammonia/water units, please refer to the manufacturer):

- If the absorption chiller will operate from steam at around 8 barg or hot water at 170-180°C (most likely if the CHP is likely to be a gas turbine with heat recovery), – the heat demand equals the cooling demand divided by 1.2.
- If it will operate from medium pressure hot water at 85-130°C or steam at around 1 barg (from a gas turbine, the exhaust of a larger reciprocating engine, or from a special, high temperature engine) – the heat demand equals the cooling demand divided by 0.68.

SIZING WITH CHP
(continued)

Step 6
Quantify your other site heat demands

Quantify your other site demands. This can be done by examining all of the heat loads that could be supplied by the CHP unit, and determining a base-load requirement in just the same way as for the cooling demands. However, in most situations, a boiler will already supply the heat, and the required information can be obtained by considering the boiler load pattern and the fuel consumption.

As a general rule, the appropriate load would be the summertime load of the boiler, taking into account variation between day and night times.

Step 7
Calculate your new total heat demand

Add together the base-load heat demands from steps 5 and 6.

Step 8
Compare base-load heat and electricity demands

Compare the base-load electrical and heat demands that you have calculated in steps 3 and 7. Express them as a ratio of heat to power.

Step 9
Do you have the right ratio of heat to power?

Consider the type of CHP unit indicated in Step 4 as being most appropriate for your site. The typical ratios of heat output to electricity output for different types of CHP unit are:

- For reciprocating engines: 1.7 to 1
- Gas turbines: 1.5 to 1, or up to 5.5 to 1 with supplementary firing of the exhaust gases.

Compare these with the ratio you have calculated for your site.

Yes

The initial sizing is close to the optimum, and absorption cooling is likely to make the CHP project more attractive.

No, but it is close

If either the heat or electrical demand is close to the ratio, it is worthwhile to review the above calculations with slightly different base-load assumptions at Step 1 or Step 5.

No, but *if I do not include heat for the absorption chiller, it does*

If your conventional heat loads give the right ratio of heat to power, addition of absorption cooling is not appropriate.

No, *the electrical output is too high*

If the potential electrical output is too high, you could consider exporting the excess electricity. Alternatively, the size of the absorption chiller could be reduced, and the optimum size will be indicated by a matching heat to power ratio. In this instance, conventional mechanical compression cooling may be required to meet the balance of the cooling demands, and the electrical load will be increased proportionately.

No, *the heat output is too high*

If the potential heat output is too large, the proposed size of the CHP unit may be reduced.

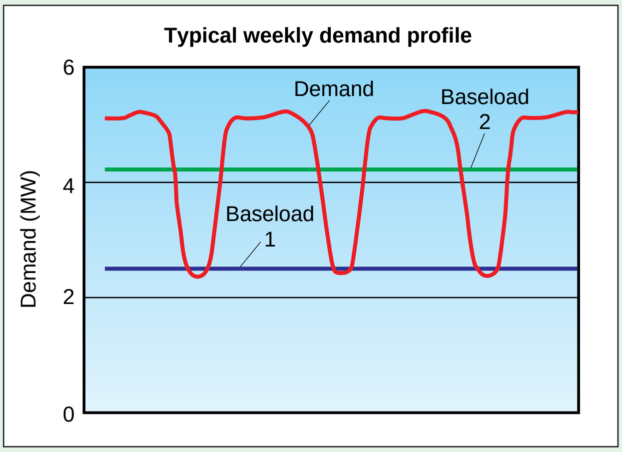
In order to establish the optimum size CHP and absorption units, it may be necessary to repeat steps 3 onwards several times to arrive at the best answer. It may also be sensible to look at the effect of small changes in some assumptions - a sensitivity analysis.

SIZING WITH CHP EXAMPLE

Worked example - sizing absorption cooling with CHP

A site operates for seven days a week. It has a cooling demand of 800 kW. The cooling is provided as chilled water, from an existing, old chiller, and a single 800 kW (cooling) lithium bromide absorption chiller is being considered in conjunction with CHP.

The chart below shows the typical electrical demand for a week, and this profile is more or less constant across the year.



The electrical demand profile tells us that the constant baseload is approximately 2.5 MW (Baseload 1). However, if the night load is excluded the baseload is approximately 4.2 MW (Baseload 2).

The site does not have sufficient sub-metering to allow the cooling plant's electrical profile to be established.

The site also has a fairly constant heat demand of 2 MW, in the form of hot water at 130°C.

Calculating the new electrical baseload

As there is no sub-metering, the electrical demand for cooling must be estimated. To do this, the cooling demand must be divided by an appropriate factor. For a chilled water system, this factor is 4.

Therefore:

cooling load = cooling demand in kW/4

800 kW(cooling /4

= 200 kW(elec)

Therefore, 200 kW must be subtracted from the baseloads above:

Baseload 1

2.5 MW - 200 kW

= 2.3 MW(elec)

Baseload 2

4.2 MW - 200 kW

= 4.0 MW(elec)

From the baseload profile, it can be seen that one or more reciprocating engines switching off every night could produce a baseload of 4.0 MW(elec). A gas turbine could be used to provide the constant baseload (Baseload 1), but as steam is not required, a reciprocating engine unit will be more appropriate.

Compare cooling demand and heat demand

A lithium bromide absorption chiller and a reciprocating engine system seem appropriate. The water temperature produced from a standard reciprocating engine will be at approximately 90°C, and the return temperature must be 80°C. The cooling demand must be divided by 0.68 in order to convert to heat demand.

800 kW(cooling)/0.68

= 1.176 MW(heat)

The site heat load has already been defined at approximately 2 MW. Therefore, the total heat demand is:

2 MW + 1.176 MW

= 3.176 MW(heat)

Compare possible output with electrical demand

Base load	= 4.0 MW(elec)
Heat base load demands	= 3.18 MW(heat)
Ratio of heat:electricity	= 0.8:1

Therefore, although a reciprocating engine CHP system rated at 4.0 MW(elec) would be justified from the electrical base load, the heat could not be utilised. As the heat:electricity ratio for a reciprocating CHP unit is about 1.7:1.

Without absorption cooling, the largest unit for which heat could all be used is about

2.0 MW(heat)/1.7

= 1.2 MW(elec)

With an absorption chiller, the heat demand is increased, and the corresponding electrical output could be

3.18 MW(heat)/1.7

= 1.9 MW(elec)

As CHP is rarely economically justified unless the heat output is well utilised, absorption cooling makes it possible to install a 1.9 MW(elec) unit rather than a 1.2 MW unit. If the absorption unit replaces a conventional chiller, it will also reduce the site's electrical load by about 200 kW. In this example, consideration of absorption is worthwhile.

Absorption Cooling with Steam Turbine CHP

A special situation exists where a steam turbine is producing electricity from high-pressure steam. The low-pressure steam from the turbine is usually either supplied to heat consumers, or condensed.

In many older steam turbine CHP installations, downstream steam consumption has decreased over the years, leaving the turbines under-utilised. Steam condensers usually reject the heat of the condensing steam into condenser water, and hence to the atmosphere.

Absorption cooling can be applied to increase the steam demand from a steam turbine, or use heat that is normally wasted in a condenser.

The amount of cooling available varies according to steam conditions:

- at about 8 barg, each tonne/hour of steam will produce about 700 kW of cooling (double effect unit, COP approximately = 1.2);
- at 1 barg, each tonne/hour will produce about 410 kW (single effect unit, COP approximately = 0.68).

The additional electricity generated will depend upon the characteristics of the steam system and turbine. For an existing turbine, it may be estimated pro-rata from the turbine's present performance.

Falling steam demand at Van den Bergh's margarine factory meant that the new heat loads were needed to keep its CHP system viable. An ammonia/water absorption chiller operating at -23°C in series with the Company's existing conventional ammonia refrigeration system restored its steam demand and heat:electricity balance.

Enhancing Hot-weather Output

Gas turbines and, to a lesser extent reciprocating engines, lose output during hot, summer weather. Cooling of the intake air (potentially from absorption cooling) can boost electrical outputs at these times.

It will rarely be economic to install an absorption chiller specifically for this duty in the UK, but it could be a way of using surplus capacity at times of low cooling demand, or it may justify a slightly larger absorption chiller. Where this is a possibility, it should be discussed with the gas turbine (or engine) manufacturer.

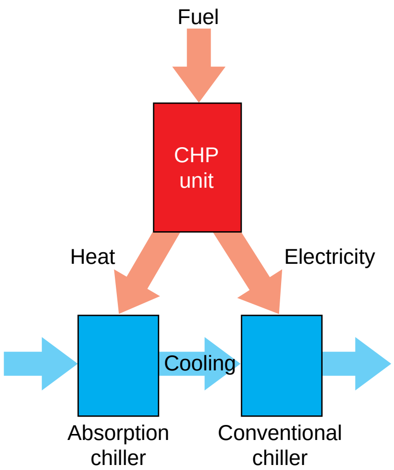
CHP and Absorption for Cooling Alone

It is possible to envisage an installation where absorption cooling, conventional cooling and CHP are used together for a cooling load alone. The CHP unit would generate heat for an absorption chiller and electricity for a conventional refrigeration plant. If the conventional refrigeration plant takes care of load variations, surplus electricity will be available for other uses.

An initial sizing can be based on the cooling load you wish to serve using these rules of thumb:

- at chilled water temperatures, the electrical output of the CHP unit should be equivalent to about 20% of the calculated cooling load in kW;
- the conventional chiller, consuming all of the electrical output would be rated for 80% of the cooling load. The absorption chiller for the remaining 20%.

At lower temperatures, the CHP unit would be larger.

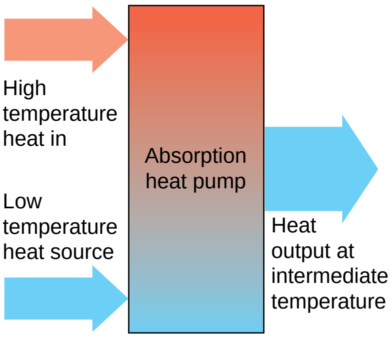


5

OTHER APPLICATIONS OF ABSORPTION TECHNOLOGY AND ADSORPTION COOLING

The absorption cycle's main application has been in cooling. However, the process can be applied in other ways: as a heat pump and a temperature amplifier.

ADsorption cooling is a related technology that is under development, and may provide an alternative to absorption cooling in some situations.

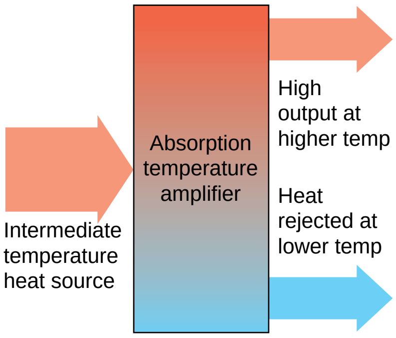


Absorption Heat Pump

A heat pump is any refrigeration system where useful heat is delivered from the condenser. In most applications, heat is taken from one, lower temperature (in the evaporator) and delivered at some higher temperature (in the condenser - and from the absorber in an absorption unit).

In a mechanical vapour compression heat pump, the driving energy is usually provided by an electric motor. In an absorption heat pump, the driving energy is provided by a higher temperature heat source, as shown in the diagram below

A small number of absorption heat pumps are in operation.



Absorption Temperature Amplifier

A temperature amplifier is a special case of a heat pump, where the only heat source is at an intermediate temperature, and the object is to produce heat at a higher temperature. In this arrangement of the cycle, a proportion of the heat will be rejected at a lower temperature.

A small number of temperature amplifiers are in operation.

ADsorption Cooling

ADsorption cooling can be said to be related to absorption cooling, because many of the principles are similar. However, the cycle exploits the ability of some substances (such as activated carbon) to adsorb a refrigerant vapour. Applying heat to the adsorbent reverses the adsorbing process.

Working examples of this technology exist, and commercial applications are under development.

6

MAINTENANCE AND RELIABILITY

Although absorption cooling is a long-established technology, it is relatively unusual in the UK, and most potential users will not be familiar with the particular maintenance requirements of an absorption chiller. The following paragraphs outline these issues.

Vacuum

Lithium bromide/water units use water as the refrigerant. The water inside the unit will be boiling at temperatures around 3°C, and condensing at temperatures only a little above ambient. To achieve this, the units operate under high vacuum.

If the vacuum degrades, the unit will cease to function properly. Thus, it is advisable to monitor the vacuum level closely, and restore it using a vacuum pump when necessary. After any service work that requires the unit to be opened, the vacuum must always be restored, and the unit re-sealed.

The Royal Free Hospital monitors the vacuum in its absorption chillers routinely. Also, as a precautionary routine, the hospital purge the unit, i.e. restore the vacuum, monthly. This is carried out by on-site technicians.

Overheating and Overcooling

Control of the input of heat and condenser water supply temperature is vital to reliable performance of a lithium bromide/water absorption chiller. Specific control provisions will vary amongst manufacturers, but it is important that the manufacturer's recommendations are met and that the integrity of these controls is maintained.

Condenser Water Temperature

Absorption units usually require condenser water to be supplied between 20 - 35°C. Some manufacturers limit the upper temperature to 32°C. The supply temperature must be neither too low, nor too high. Check the permissible range with your supplier.

The absorption chiller manufacturer will normally specify the rated cooling duty at a particular condenser water return temperature, say 28°C. If higher condenser water temperature of say, 35°C is used, the COP will be reduced, and the cooling duty will be reduced to 65%. Since this will usually occur in hot weather, it is important to be aware of the expected reduction in output.

Heat rejection

Cooling towers are the traditional means of rejecting heat from absorption chillers. They have the lowest initial capital cost and provide the most effective means of dissipating heat. This is because their operation is dependent upon the ambient wet bulb temperature, rather than the dry bulb temperature. During summer in the UK, the wet bulb temperature is usually about 6°C below the dry bulb, and a condenser water temperature of 28°C can easily be achieved.

However, there are well-known difficulties with the use of cooling towers, and these, together with an alternative, are discussed in Heat rejection options below.

HEAT REJECTION HARDWARE

Heat rejection options

Cooling towers (direct and indirect)

An open-circuit cooling tower operates by inducing or forcing air to flow through a matrix that is wetted by the condenser water, circulated to and from the chiller. A proportion of the water evaporates into the air stream enabling heat to be rejected as latent energy in the water vapour.

In a closed (or indirect) circuit cooling tower, the evaporating water and the condenser water from the chiller are kept in two separate circuits. The condenser water from the chiller passes through a heat exchanger within the cooling tower. It is cooled in the heat exchanger by the evaporation of water in the cooling tower.

Cooling towers take advantage of lower condensing temperatures

In both types of cooling tower, a supply of fresh water is provided to make-up the losses due to evaporation. As a guide, for every kW of heat rejected, approximately 1.5 litres/hour of water will be evaporated. In addition to the fresh water needed to make up the evaporative losses, typically a further 5% is required to replace the residual water, which is concentrated with impurities and chemical treatments from the evaporated water. A balancing quantity of water must be disposed to drain.

For all cooling towers, treatment of the water is necessary to inhibit corrosion and to limit the deposition of insoluble mineral salts. Biocide treatment is essential to combat Legionella and other bacteria that thrive in slow moving or stagnant water contaminated with sludge, algae or organic material at temperatures commonly encountered in cooling towers. This treatment can be made using chemicals or ultraviolet systems.

All evaporative cooling towers must be registered with the local authority and a strict programme of treatment and maintenance must be provided and documented to control the risk of Legionella.

An alternative - dry air and spray assisted coolers

Dry air coolers require minimal maintenance (except cleaning) and provide an alternative to cooling towers. They consist of banks of air cooled heat exchangers rather like car radiators. However, the initial capital cost is higher then cooling towers, and more space is required. They also produce more noise.

These coolers can impose limitations on the absorption chiller in periods of high ambient temperature. Careful specification is necessary to ensure that the absorption units can function properly under the expected range of temperature conditions.

During very hot spells, it is possible to provide improved cooling, using the evaporation of fresh, mains water sprayed into the air stream. The spray system needs careful design to avoid hazards from over-spray and consequent standing water.

Dry coolers normally have a higher power demand than cooling towers, but avoid the costs of make-up water and water treatment.

Dry coolers also require protection from low temperatures in winter. It is customary to add an anti-freeze agent to the water circuit to prevent freezing.

Size and rating of dry coolers

Dry air coolers are a series of finned heat exchanger units, each having an axial fan. The units are arranged in modules to give the required capacity and can be mounted with the fan axis either horizontal or vertical to suit the intended location.

Each fan/heat exchanger unit is typically between 1 - 1.4 metres square although other sizes are possible. Some manufacturers use vee configurations to give horizontal air inlet and vertical air outlet.

The rating or cooling capacity of a fan/heat exchanger unit depends upon the surface area (physical size), air velocity, required fluid entry and exit temperatures, fluid properties and the ambient temperature. The manufacturer will usually specify the duty for a standard set of conditions and apply correction factors to determine the duty at other conditions.

Dry coolers avoid the need for water treatment

Availability of Spares and Maintenance Service

Potential users of any technology that is not widely used will naturally be concerned that the equipment they may buy will be adequately supported in terms of spare parts and maintenance services. This will be particularly true if the equipment is manufactured overseas.

For this Guide, in 1998 a survey of suppliers of absorption chillers was carried out in the UK. The results indicated that adequate support is available, but that the quality of this support varies between suppliers, and in different parts of the country. Thus, it is important to investigate, at the tender stage, the support offered by suppliers.

Heat Exchanger Fouling

All heat exchangers are subject to fouling by limescale, biological growth and dirt. This applies to conventional refrigeration as well as to absorption units. An absorption chiller contains at least four heat exchangers handling external fluids, in addition to the external heat rejection by cooling towers or dry air coolers.

The most vulnerable item is the cooling tower and the associated circuit, although the treatment regimes prescribed to combat legionella normally include treatment to protect the circuit from corrosion and all deposits except physical dirt. Strainers are usually employed with open circuit towers to prevent dirt fouling heat transfer surfaces (e.g. the condenser and absorber cooling-coil within the absorption chiller).

Dry air coolers are also subject to deposition of atmospheric dirt, and a regular cleaning regime is recommended. Dirty surfaces will downgrade the ability of the cooler to reject heat, eventually affecting the performance of the absorption chiller. Where spay assistance is added, cleaning is particularly important.

The heat exchangers inside the absorption chiller that are most vulnerable to fouling are:

- the evaporator (from the cooled fluid);
- the heating coil (from the steam, hot water or burner supplying the heat);
- the absorber cooling coil (from condenser water);
- the condenser (from the condenser water).

Conventional water treatment regimes for hot and chilled water distribution systems and for steam boilers will provide adequate protection for fluid heat exchangers. Just as for conventional chillers, cleaning will only be required if the water treatment regimes fail.

The combustion system in direct fired chillers will require routine inspection, just as boilers do. Cleaning of the combustion surfaces is more likely to be required for oil fired units than gas fired ones.

> The absorption unit at Van den Bergh's plant uses cooling water from a nearby river. After eight months operation, heat exchangers in the cooling water circuit were inspected and found to be in good condition, although a large quantity of dirt had to be removed. A regular cleaning regime has been established to maintain optimum performance.

Corrosion

Lithium bromide solution, chilled water and condenser water are all corrosive.

Lithium bromide will be supplied with inhibitors to limit corrosion, but regular (say, twice-yearly) checks on the chemical composition of the solution are sensible. Slow corrosion by inhibited lithium bromide will produce non-condensable gases, which will cause a very gradual loss of vacuum. If vacuum degrades more quickly than the manufacturers expect, this can provide early warning that corrosion is occurring.

The chilled water and condenser water circuits should also be protected against corrosion, using conventional treatments. As for all water distribution systems, regular checking is required.

Handling and Disposal of Refrigerants etc.

Almost all refrigeration systems contain refrigerants, oils, etc. that are potentially subject to the Control of Substances Hazardous to Health (COSHH) and waste disposal regulations. This is also true of pipework systems containing glycol and other anti-freeze solutions.

Absorption chillers contain either lithium bromide or ammonia with water. Of these, only ammonia is covered by the COSHH regulations' occupational exposure limits (as published in the associated document EH40 - 1998 edition, revised annually).

However, lithium bromide is usually supplied with corrosion inhibitors, which may be covered by the regulations, thus making lithium bromide solution a special waste. Some corrosion inhibitors are carcinogens. Again, advice should be sought from the suppliers, or from the supplier of the solutions (see Appendix B).

Pressure Systems Regulations

The UK *Pressure Systems and Transportable Gas Containers Regulations 1989* apply to most engineering equipment where pressure is applied.

The regulations apply to all steam systems and to all conventional refrigeration systems with a compressor drive motor over 25 kW. For absorption cooling, it is clear that the regulations apply to all ammonia/water systems, and to lithium bromide systems where the heat is supplied at over 100°C. It is possible to envisage lower temperature units and direct gas fired units where the regulations will not apply if the pressure is guaranteed to be below 0.5 bar gauge.

It is recommended that those concerned with application of the regulations purchase COP 37 and HS(R)30 (see Appendix B). However, the following gives a brief summary of the implications of the regulations.

These regulations place certain duties on the user of applicable plant, and on the suppliers and installers. The user's obligations may be summarised as:

1. Ensure that the system is correctly operated and maintained.
2. Establish safe operating limits (i.e. the limits of temperature and/or pressure) as on the most recent report of the competent person, manufacturer's certificate or existing operating limits if never previously examined.
3. Decide if the system is major/intermediate/minor, as defined by the regulations.
4. Have a suitable *Written Scheme for Examination* of the pressure vessels and protective devices prepared or approved by a Competent Person. Include pipework if, on advice of the Competent Person, integrity is liable to be reduced by corrosion, erosion etc. and the service and location are such that failure could give rise to danger.
5. Have regular examinations carried out by your Competent Person, according to the written scheme for examination.

It will be clear that the supplier and installer have most of the important information available. Potential users of any refrigeration technology should obtain as much of this information as possible from the suppliers and installers to assist in meeting the user's obligations. It may be appropriate to ask your suppliers or installers to prepare the Written Scheme for Examination for you, although this will need to be endorsed by your Competent Person.

You should also obtain an undertaking that the suppliers' and installers' obligations will be met.

Other Regulations

Absorption cooling is not especially affected by other regulations, but as for all engineering projects, the purchaser should ensure that the requirements of CE marking, the Health and Safety at Work Act and the Construction Design and Management (CDM) Regulations are met. These will apply to the design, installation and commissioning phases, and to some maintenance activities.

Maintenance Costs

Costs for maintenance should not be expected to be very different to those for mechanical vapour compression units. In the medium term, any extra time required for monitoring and maintaining vacuum on lithium bromide/water units is balanced by the need to maintain or replace fewer moving parts. An estimate of costs is included in *Calculation of financial benefits - operating costs* on page 30.

The lithium bromide/water absorption chillers at the Royal Free Hospital have been operating for three years. The hospital advise that maintenance costs are lower than for its previous conventional chillers.

7

PUTTING A FINANCIAL CASE TOGETHER

The following Guides explain this topic in more detail:

GPG 69 *Investment Appraisal for Industrial Energy Efficiency*

GPG 227 *How to Appraise CHP - A Simple Investment Appraisal Methodology*

GPG 236 *Refrigeration Efficiency Investment - Putting Together a Persuasive Case*

The general Guide GPG 69 describes methods of comparing the costs and benefits of a proposed project, and GPGs 227 and 236 provide more detail for their specialist areas.

A financial case for absorption cooling will generally include a comparison with conventional cooling. In this section, we provide tools to help carry out this comparison, together with a worked example, that you can follow to aid calculations.

Capital and Operating Costs

The first step is to collect data on capital costs. The following technical section gives information on major capital items that can be used for an initial feasibility analysis and to justify further investigation.

The data presented in this Guide should not be used for final justification of capital expenditure. Quotations from suppliers and installers should be obtained before firm commitments are made.

Secondly, it is necessary to establish the costs of operating the absorption chiller. Again, the following technical sections indicate these costs, and the worked example will assist you in carrying out the calculation.

It is also sensible to carry out a sensitivity analysis, i.e. to repeat the calculation with different cost assumptions. Most projects are very sensitive to changes in the relative prices of heat and electrical power. In the worked example, a modest increase in the electricity price makes a vast improvement to the financial case, whichever evaluation criteria are applied.

Evaluating the Benefits - Simple Payback

Payback is defined as the period after which the cumulative cost savings equal the capital cost of a project. It is often called simple payback because it requires no assumptions about the project in terms of timing, plant lifetime or interest rates.

Evaluating the Benefits - Differential Payback

A refinement of the payback method, applicable when comparing two alternatives (such as conventional or absorption cooling) is the differential payback. This method uses the difference between the capital and operating costs of competing projects, rather than the total costs. This is useful to justify additional expenditure if additional savings are available.

Simple and differential paybacks are widely used because they are simple, practical and easily understood. The two methods are also very effective in summarising the conclusions of initial assessments.

The major disadvantage is that payback places too much emphasis on short-term cash flow. Absorption chillers may have paybacks longer than two years, particularly if associated with CHP plant, but will continue to contribute savings for many years. Thus, absorption cooling or CHP might be unwisely disregarded if appraised on payback criteria alone.

ESTIMATING COSTS

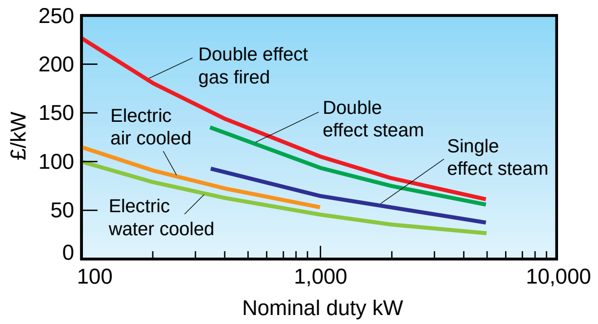
Capital costs

Note: The capital costs given below should only be used for preliminary evaluations. Depending upon many circumstances, all, and particularly those relating to installation costs, may not be accurate.

Chillers

As the capacity of all water chillers increases, the cost per kW of duty decreases. Costs also vary considerably from one supplier to another, and when the requested operating conditions differ from standard conditions. Typical costs per kW of nominal duty are shown in the graph below as a guide to enable comparisons. Actual selling prices may be up to 50% higher from some suppliers.

Capital cost of water chillers



When using single effect absorption chillers operating on hot water, the output may have to be down-rated as detailed in *Sizing your absorption chiller - factors to take into account* on page 12. An example, for a 1,000 kW single effect chiller, is shown below.

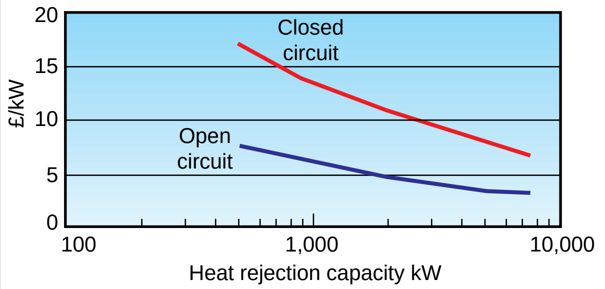
	High temperature	Low temperature
Actual cooling duty (kW)	1,000	1,000
Source/return temperature	115/105°C	90/80°C
Downrating factor	1.0	0.5
Nominal duty required (kW)	1,000	2,000
Cost (£/kW)	70	50
Cost	£70,000	£100,000

Cooling towers

The cost of cooling towers follows a similar relationship to chillers, i.e. the larger the capacity, the smaller the cost per kW. Closed circuit cooling towers are more expensive than open circuit types due to the cost of the heat exchanger that separates the two circuits.

The costs shown in the graph below relate to the cooling capacity or heat rejection capability of the cooling tower and not the chiller, as detailed in Heat rejection - quantities on page 9. The graph assumes that the rules suggested in “Heat rejection - temperatures” are followed.

Cost of wet cooling towers



The capital cost of providing water treatment must be added to the cooling tower cost. A chemical dosing system has a capital cost of around £6/kW and there are significant running costs for the chemicals.

Alternatively, a chemical free system using ozone treatment costs around £22/kW for a 2,000 kW system. This is more expensive to buy, but has lower running costs and avoids the complications of storing chemicals.

Dry Coolers

The specific cost of dry air coolers is dependent upon the design conditions rather than the size of the installation. Since systems are made up from a number of modules, there is little economy of scale with large capacity installations and the cost per kW of heat rejection does not reduce significantly.

For designs based on 5°C temperature difference between the ambient air and return condenser water, 5°C difference in the flow and return temperature and using a 20% glycol solution, the cost ranges from around £30/kW for units with high speed fans to £70/kW for units with quieter, low speed fans. If the temperature difference between the air and return water is increased to 10°C, the cost will be reduced by around 40%. However, this will reduce the maximum ambient temperature capability by 5°C.

As described in Heat rejection options on page 24, to cope with high ambient temperatures, spray assisted cooling will often be necessary. It is advisable to obtain specific prices from manufacturers when choosing this system.

Other installation costs – per kW	
Steam pipework (per kW of heat)	£8
Condenser pumps and pipework (per kW of heat rejection)	£10
Chiller transport and offloading (per kW of cooling	£10
Building work (per kW cooling)	£20
Electrical (per kW of electrical supply)	£15
Substation (per kW of electrical supply)	£50

ESTIMATING COSTS
(continued)

Operating costs

Heat source

When the absorption chiller is directly fired, the cost of the heat per kWh can be easily determined from the fuel cost. If a fuel-fired boiler is used, this cost is divided by the boiler efficiency, typically 0.8.

In applications using CHP, it is necessary to apportion costs between the power generated and the heat produced. The costs of operating the CHP unit will include the fuel cost, the maintenance cost and, possibly, a capital recovery cost distributed over the expected lifetime of the plant.

The cost of heat

If figures for the cost of heat are not readily available, guidance on these is provided in Energy Consumption Guides 66 and 67 (available from ETSU - see Appendix B).

It is sometimes difficult to allocate the operating costs of a CHP unit between heat and electricity. The technical paper 'Thermoeconomics applied to air conditioning with cogeneration' (see Appendix B) provides one method.

Electricity

The electricity consumed by the absorption chiller can be obtained from the manufacturer's data. For steam and hot water driven lithium bromide chillers, it is usually about 7 W/kW of chiller capacity to power for auxiliary equipment.

In addition, the power consumed by the condenser water pump is about 22 W/kW of heat rejected by the cooling tower, assuming a pressure drop of 360 kPa and 6°C temperature drop. The heat rejected is obtained by multiplying the chiller capacity by the heat dissipation ratio (see *Heat rejection - quantities* on page 9) to give the total pump power.

Maintenance

Maintenance contracts are available whereby the supplier provides remote monitoring of the absorption chillers, quarterly service visits and same day attendance if a fault occurs. The typical annual cost is £5/kW of cooling capacity.

If major components have to be replaced, there is an additional cost. Similar costs can be used for equivalent electric chillers, unless the history of electric chiller maintenance costs is known for the site.

Cooling towers

The typical costs of operating cooling towers are given in the table below. Actual water and electricity prices should be used in any financial evaluation. The water supply cost assumes that it is metered and allows approximately 5% disposal to foul drain.

Dry Coolers

Dry coolers have minimal maintenance cost and the operating cost can be taken from the electrical power consumed. A typical power consumption rate, for evaluation purposes, is 25 W/kW of heat rejected. The power consumption depends upon the speed of the fans. Variable speed control will give significant savings by reducing the air velocity as the ambient temperature falls.

Operating costs for cooling towers			
		W/kW	p/kWh
Water consumption	Water supply at £0.5/m^3		0.08
Chemical treatment			0.04
Cleaning and maintenance			0.02
Fan power	Electricity at 4p/kWh	10	0.04
Total cost p/kWh of heat rejection			**0.18**

Evaluating the Benefits - NPV and IRR

Net Present Value (NPV) and Internal Rate of Return (IRR) are both techniques that overcome the disadvantages of simple payback for evaluating projects. They are both particularly useful when comparing high investment, long-term projects with one another.

Both are discussed fully in GPG 69, but as they are particularly useful for comparisons of competing technologies such as conventional and absorption cooling, the following provides a brief description.

Evaluating the Benefits - Life Cycle Costing

Considering the use of NPV and IRR, makes it possible to apply life cycle costing of projects. Life cycle costing simply means considering the NPV or IRR over the entire life of the proposed plant. This is realistic, because once the initial investment is paid back, the plant will continue to generate savings until it is worn out. Conversely, a competing, less efficient choice will continue to cause excess costs for its whole life.

In the following worked example, a target of a two year payback would have meant that the project was turned down. However, NPV and IRR show that over a 15 year life, an absorption chiller would be a very good investment

The reasonable expected life for both absorption and conventional, mechanical vapour compression chillers is about 15 years. There are many examples of older units of both types still in efficient operation. If the cooling system that will be served by the cooling unit is expected to have a long life, 15 years would give a fair basis for comparison.

FINANCIAL EVALUATION

Discount factors, and NPV and IRR

It is better to be given, say £1,000, now than in five years time, because you could invest it and it will be worth more in five years time.

Discount factors provide a method of allowing for a consequence of this fact: instead of being invested in new plant, money could be invested in a bank or on the Stock Exchange and would earn interest. A discount factor is directly equivalent to an interest rate, but applied backwards - to work out what some future amount is worth now, rather than what an amount now will be worth in the future.

The NPV method considers all of the cash flows from the project year by year, and applies a discount rate to each one. Then all of the reduced amounts are added to arrive at the overall value of the project. This is best illustrated by example, as in the worked example on page 33.

The IRR is the discount rate at which the NPV is zero. To calculate this, simply calculate the NPV at several discount rates, until the right discount rate is found. A graph can help, as shown in the worked example on page 34.

Although IRR is harder to calculate, it presents a single number (a discount rate, comparable with interest rates) that allows different projects to be compared with one-another, and with alternative investments

COSTING EXAMPLE

Worked example - calculation of costs and savings

In this example, a user who has a need for additional cooling is considered. The Company is considering an 800 kW, single effect absorption chiller, operating on hot water entering at 115°C, leaving at 105°C and generated by a waste heat boiler. It will operate, serving a process, on a base load, 24 hours/day 7 days/week (taken as 8,000 hours/year). The alternative is a conventional chiller of the same size, which will be added to the existing installation. As either the new or existing chillers will provide the equivalent load, the operating hours are the same.

All costs are taken from the previous technical sections, but costs that are common to the two systems (e.g. chilled water pipework and pumps) are omitted.

The conditions given for the absorption chiller indicate that the heat dissipation ratio is 2.47. The conventional alternative, and the existing plant has a COP of 4.5, so the heat dissipation ratio is 1.22 (see *Heat rejection - quantities* on page 9).

The heat rejection system (for either option) is a new open cooling tower with chemical treatment. The cooling tower for the absorption system requires 2,000kW (800 x 2.47) cooling capacity, the conventional plant only requires 1,000kW (800 x 1.22) cooling capacity.

The cost of the heat from the waste heat boiler for the absorption chiller is related to the capital and operating cost of the boiler and hot water pump, and set at 0.25p/kWh. Electricity is 4p/kWh.

Capital costs

	Absorption		Conventional	
Item	**Calculation**	**Result**	**Calculation**	**Result**
Chiller	£70 x 800kW	£56,000	£50 x 800kW	£40,000
Cooling tower	£5.00 x 800kW* 2.47	£9,880	£6.20 x 800kW* 1.22	£6,050
Chemical dosing	£6 x 800kW* 2.47	£11,900	£6 x 800kW* 1.22	£5,856
Heat supply pipework	(800kW/0.68) x £8	£9,400	N/A	N/A
Condenser pumps	(2.47 x 800kW) x £10	£19,800	(1.22 x 800kW) x £10	£9,760
Chiller transport and offloading	£10 x 800kW	£8,000	£10 x 800kW	£8,000
Building work	£20 x 800kW	£16,000	£20 x 800kW	£16,000
Electrical (main)	£15 x 7W/kW x 800kW/1,000	£84	£15 x 800/4.5kW	£2.666
Electrical (auxiliary) ie heat rejection pumps and fans	£15 x (22 + 10)W/kW x 800kW x 2.47/1,000	£984	£15 x (22 + 10)W/kW x 800kW x 1.2/1,000	£460
Substation	£50 x (5.6 + 63)kW	£3,430	£50 x (800/4.5 + 30)kW	£10,388
Total capital cost		**£135,442 say £150,000**		**£99,159 say £110,000**

Running costs

	Absorption		Conventional	
Item	**Calculation**	**Cost**	**Calculation**	**Cost**
Maintenance	£5 x 800kW	£4,000	£5 x 800kW	£4,000
Cooling tower running cost	8,000hrs x (2.47 x 800kW) x £0.0018	£28,500	8,000hrs x (1.22 x 800kW) x £0.0018	£14,054
Heat source	8,000hrs x (800kW/0.68) x £0.0025	£23,600	N/A	N/A
Electrical (main)	8,000hrs x 7W/kW x 800kW/1,000 x £0.04	£1,792	8,000hrs x 800kW/4.5 x £0.04	£56,889
Electrical (auxiliary)	8,000 x 22W/kW x 800kW x 2.47/1,000 x £0.04	£13,911	8,000 x 22W/kW x 800kW x 1.22/1,000 x £0.04	£6,871
Total running costs		**£71,803**		**£81,814**

Difference in capital cost between conventional and absorption = absorption chiller is £40k more expensive.

Annual operating cost saving with absorption chiller is £(81,814 - 71,803) = say £10,000.

Note: The absorption chiller is similar to that quoted in *Sizing with CHP* example on page 20. In that case, the calculation would have to include the extra cost of a 1.6 MW CHP unit compared to a 1 MW unit, and also the additional value of the 600 kW of electricity generated. These additional calculations are described in GPG 227

FINANCIAL EVALUATION EXAMPLE

Worked example - calculation of payback, NPV and IRR

The data for this example is based on the example from the previous page, where the capital and operating costs for an absorption chiller and a conventional chiller are calculated.

Differential payback

The differential payback is the additional capital cost, divided by the difference in annual costs (i.e. annual savings):

£40,000 / £10,000 per year = **4 years**

Net present value (NPV)

For NPV, it is assumed that the Company has set 20% as the discount rate. The Company has accepted the concept of life-cycle costing, and so the period considered is 15 years. It is necessary to tabulate the savings, as shown below.

As we are assessing the savings available from using an absorption chiller rather than a conventional chiller, it is appropriate to base the calculation on the differences in costs over the period.

Year	Cashflow £k	Discounted cashflow £k
0	-40	-40
1	10	8.33
2	10	6.94
3	10	5.79
4	10	4.82
5	10	4.02
6	10	3.35
7	10	2.79
8	10	2.33
9	10	1.94
10	10	1.62
11	10	1.35
12	10	1.12
13	10	0.93
14	10	0.78
15	10	0.65
Total	**110**	**6.75**

[The discounted cashflow is calculated by multiplying the actual cashflow in the year by $((1 / (1 + r)^n)$, where r is the discount rate (as a fraction, i.e. 0.20 rather than 20%), and n is the year number. These calculations are also available as look-up tables, and as spreadsheet functions.]

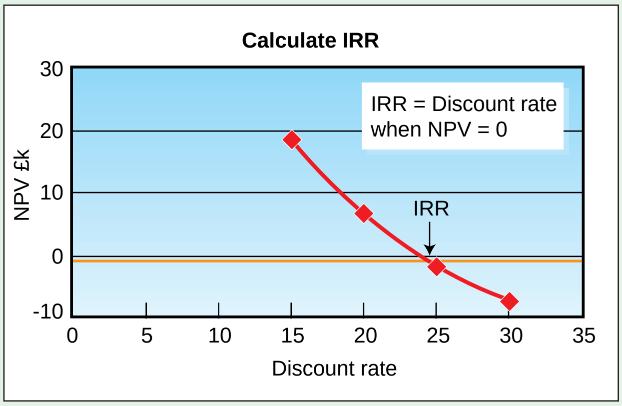
In most organisations, a positive NPV will justify a project - here, the value of the additional expenditure on an absorption chiller is +£6,750. This indicates that in this case, absorption cooling is a good investment.

In a situation where several projects are competing for limited cash, the one with the highest NPV will normally be favoured. In this case, the benefits of the additional expenditure for an absorption chiller over a conventional alternative have been evaluated. In this case, the NPV will indicate the benefits of this additional expenditure compared to alternative investments.

Investment rate of return (IRR)

To calculate IRR, it is necessary to extend the table to calculate the discounted cashflow at a number of discount rates, and identify the discount rate that gives an NPV of zero. This can be done from a simple graph, as indicated below. As for NPV, the IRR is calculated on the additional expenditure.

Year	Rate = 30%	Rate = 25%	Rate = 20%	Rate = 15%
0	-40	-40	-40	-40
1	7.69	8.00	8.33	8.70
2	5.92	6.40	6.94	7.56
3	4.55	5.12	5.79	6.58
4	3.50	4.10	4.82	5.72
5	2.69	3.28	4.02	4.97
6	2.07	2.62	3.35	4.32
7	1.59	2.10	2.79	3.76
8	1.23	1.68	2.33	3.27
9	0.94	1.34	1.94	2.84
10	0.73	1.07	1.62	2.47
11	0.56	0.86	1.35	2.15
12	0.43	0.69	1.12	1.87
13	0.33	0.55	0.93	1.63
14	0.25	0.44	0.78	1.41
15	0.20	0.35	0.65	1.23
Total	**-7.32**	**-1.41**	**6.75**	**18.47**



From the graph, it can be seen that the IRR for this project is about 24%. In most organisations, this would justify the additional investment in the absorption chiller.

In a situation where projects are competing for limited cash, the one with the highest IRR will normally be favoured. In this case, the benefits of the additional expenditure for an absorption chiller over a conventional alternative have been evaluated. The IRR will indicate the benefits of this additional expenditure compared to alternative investments.

8

PROCEEDING WITH DESIGN AND INSTALLATION

If absorption cooling seems suitable for your application, there are a number of logical stages that must be followed for any project: specification, design, installation, commissioning and acceptance. Important considerations apply to absorption cooling at each of these stages and these are described in this Section.

Things to Ask Your Supplier/Contractor

In order to ensure you buy the most appropriate unit, you should ask your supplier several key questions:

- Is the equipment CE marked? Does it comply fully with the Pressure Systems regulations and will it allow you to comply with your responsibilities under these regulations?
- What allowance is made in the designs for corrosion (this may be special tube material, thicker tubes, or both)?
- How does the system deal with crystallisation, however caused, but particularly upon power failure during the power-down cycle?
- What training will they provide for you and your staff?

Specification

The importance of a good specification cannot be overstated. Absorption cooling usually requires analysis of the interaction of cooling loads and the availability of heat, and often integration with an existing pipework system (from a waste heat source or from CHP). There are three ways of achieving this:

- specify the installation yourself;
- employ a consultant;
- build a relationship with a supplier and contractor.

Do-it-yourself specification

If you have sufficient time and confidence, this is a good way to specify a plant. You will know your site better than any contractor, and it will be possible for you to apply a full competitive tendering procedure.

If you choose this route, much of the information presented in this Guide will be helpful, and it is summarised in the technical section that follows. Having used the information provided here, you would be in a position to ask the right questions in your enquiries to prospective suppliers/installers, and understand the replies.

Competitive tendering would involve asking several - typically three - contractors to tender for the work. It has the benefits that you can be sure you are getting the plant at a good price, and also, you will have the benefit of several independent brains examining your application.

However, to work properly, competitive tendering requires a good, well-defined specification. This is time consuming, even with the information given in this Guide.

You Could Employ a Consultant

The main advantage in employing a consultant is that he should have the time to think in depth about your application. The right consultant will have experience of absorption cooling and all the associated issues. He should be able to consider all the options available, and set them down clearly in a specification, in a way that the contractors can understand.

Independence is a plus in consultants. Most have no commercial links to a hardware supplier; so you should have confidence that tendering will get you the best possible deal.

The best way to find a consultant is by recommendation. Failing that, the Institute of Refrigeration, British Refrigeration Association and CIBSE (see Appendix C) have lists, but before choosing one, it is wise to ask for details of their specific experience of absorption cooling.

An enquiry based on the consultant's specification can be put out to competitive tender. The consultant will then be able to properly assess the bids that come back, and to provide assistance at the later stages of the project.

You Could Build a Relationship with a Supplier and Contractor

This is a potential alternative to doing much of the work yourself: find a potential supplier early in the project with the minimum information suggested in the draft specification, and then work with them to develop the design.

You could chose a supplier and contractor by writing to several potential suppliers with an outline enquiry, and using their response to choose one or two to proceed with. Check that they have experience with similar installations, and that they are prepared to look at the interface with the rest of your system as well as the installation itself. In this way, you are able to benefit fully from the contractor's experience.

If the contractor is free of competitive pressures, they will have time to consider all the angles to help you find the best solution. There is also time for interaction and iteration, and they can provide unbiased advice about capital and running costs.

The disadvantage is that you lose flexibility and the competitive element at the stage of specifying the hardware because the suppliers will only offer their own equipment. You can follow this procedure with several contractors in parallel, but that can be time consuming and complex - as well as imposing competitive pressures that do not necessarily give the best result.

A second disadvantage of this system is that you would be subject to the supplier's product range, and to their biases and prejudices. They could also be tempted to think short term because there is always the temptation to minimise work and get onto the next job.

SPECIFYING PLANT

Specifying an absorption chiller

Note: The following is intended to act as a reminder of items to include in your specification, indicating the information you need to supply, and things you should remember to tell potential suppliers. Your company may have additional requirements that override or add to these.

Duty specification

This should include a clear definition of the fluid you need to cool, the flowrate and temperature range. You should also detail the heat source, in terms of its nature (hot water, gas, etc.), pressure and temperature (include inlet and outlet temperatures for hot water).

Heat rejection

Bearing in mind your organisation's policy regarding the use of cooling towers, discuss these issues with your supplier. Cooling towers represent the best overall option, but your supplier will advise on the effect of dry air coolers, with or without spray assistance.

Other items to specify

Terminal points for:

- fluid to be cooled;
- heat supply: hot water / steam and condensate/ gas/oil;
- chimney (for gas and oil systems only);
- heat rejection condenser water system;
- electrical supplies;
- civils work, bases and steelwork.

Standards and legal/regulatory requirements

You should ensure that your contractor/supplier complies with and enables you to comply with all legal and other good practice requirements, including:

- appropriate British or other internationally recognised standards;
- the requirements of CE marking;
- the Pressure Systems and Transportable Containers Regulations;
- COSHH and other Health and Safety Regulations and Legislation (it is reasonable to ask the supplier for any appropriate data sheets);
- waste disposal regulations;
- CDM regulations;
- if appropriate, BS4434 and the Institute of Refrigeration Code of Practice for Ammonia Installations.

Noise

Any noise limitation, particularly related to the heat rejection system, should be highlighted.

Training and documentation

You should advise your contractor/supplier of your training requirements, or discuss them with him. The level of training required will vary depending upon how much routine work you intend your own staff to carry out. It is suggested that the minimum is routine daily and weekly monitoring checks, which can be demonstrated during commissioning, and supported in the manuals provided. Deeper involvement will require training that is more detailed.

You should ensure that your contractor/supplier provides comprehensive manuals to accompany the plant. This should include data collected during commissioning, and the allowable ranges of cooling water and heat source temperature for future reference.

Performance testing

Review *Performance Testing* on page 39 and decide the level of testing you require. This can have a large impact on the costs of the installation.

Things to ask your contractor/supplier to provide

Estimated operating costs and TEWI

It is legitimate to ask the contractor/supplier to estimate the annual running costs for the plant (including auxiliaries such as pumps and fans), and the TEWI (Total Equivalent Warming Impact - see page 2. In order to do so, he will need to know:

- how the plant will operate - the pattern of availability of heat or requirement for cooling, depending on the basis you wish to use to control the unit;
- the cost of electricity and heat.

This information needs to be accurate if you wish to compare different bids. However, no model of future performance will ever be perfect, so try to give as good a picture as possible without too much complication.

Other items

- The provision made in the equipment for corrosion, e.g. details of tube materials and thickness, explaining the reason for the choice.
- A statement of the company's Quality Assurance policies in the factory and on site.
- An explanation of the provisions made in the design to avoid crystallisation, however caused.
- Energy saving measures that have been included in the design of auxiliaries.
- Advice of any hazards arising from the plant or the installation phase (the CDM Regulations refer).
- Maintenance support available for the plant.
- The noise levels produced by the condenser system.

Specification as Part of a CHP Package

Most CHP suppliers are now familiar with the range of standard package absorption chillers available. This means that they are well placed to specify, and even supply, the absorption chiller as part of their package.

However, CHP suppliers are CHP experts, not cooling experts. It is, therefore, advisable to ensure that their interpretation of your cooling needs, and the interaction with any existing cooling plant, is correct. An independent consultant could help in this.

The Detailed Design and Installation Phases

However the specification stage is arranged, there are three ways of arranging the detailed design and installation of the plant:

- arrange a turn-key contract:
- arrange all of the details yourself – DIY;
- employ a consultant to do this on your behalf;

A Turn-key Contract

This concept involves setting the performance expected from the plant and their terminal point (where they start and stop), and leaving all the details to the contractor. Already well established for CHP contracts, this has many advantages in clarifying contractual responsibility and minimising your own work input.

Turn-key contracts follow logically if a good relationship with a supplier or CHP supplier has been established at the specification stage, but are equally applicable however the specification has been derived.

In all cases, clarity in the original specification is of paramount importance: it is vital that you and the contractor both fully understand what is expected.

DIY Management or by a Consultant

No project can proceed without some disruption to existing services, so some interaction between the client site and the contractor is inevitable. This leads some to conclude that it would be best for them to handle peripheral work using well-proven and trusted contractors.

A consultant could also be employed at this stage, and the advantage is to limit the direct involvement by your organisation and to benefit from his experience of similar systems and appropriate legislation.

As for any engineering project, the purchaser of the equipment should be aware of his responsibilities under the CDM and other regulations that may be applicable.

In addition to the normal items that require care during the installation phase, there are a few points that require particular attention when installing an absorption chiller:

- Most units will be supplied as pre-assembled packages, charged with refrigerant and absorbing fluid, and under vacuum. Installation is the time when damage is most likely to occur, and for vacuum to be lost. Particular monitoring and care is required.
- It is also a wise precaution to ensure that a chemical analysis of the absorption fluids (solutions) is carried out before commissioning, to ensure that no contamination has occurred.
- As for conventional chillers, pipework connections will be supplied capped. This provides protection from dirt and corrosion during storage and installation, and care should be taken to retain the integrity of the seal.
- A common problem when commissioning both conventional and absorption refrigeration units, is dirt that has accumulated during pipework construction being washed into heat exchangers, causing blockage or fouling. Simple strainers fitted at strategic points and cleaned regularly during the first few days of operation can avoid this.

Commissioning

Commissioning generally falls into two parts, dry and wet. Dry commissioning relates to tests carried out without full operation of the unit concerned - control systems, safety systems, pump rotation, etc. Wet commissioning is setting the unit to work in careful steps.

In general, only the supplier or a well-trained installer can carry out dry commissioning. The client or his representatives can have little direct input. At wet commissioning, it is well worthwhile for the user to observe the tests and procedures that are carried out, as this gives a unique opportunity to understand the details of how the system operates.

It is particularly important that the supplier and/or installer allows enough time to adequately train the user's staff in the absorption chiller's operation, and to build confidence in the unit. This is best addressed at the specification stage, when it should be made clear to bidders that adequate time for commissioning and training must be allowed.

One way of achieving this is to specify and insist that detailed method statements are prepared by the contractor well in advance of commissioning, and that these are to include demonstrations of the plant at key stages of commissioning. These should include rigorous checks of:

- the response of the unit and its control system to all possible failures, e.g. chilled water flow, power failure, heat supply control (steam or hot water valve jammed open or closed), loss of control signal, etc.;
- the interaction of the chiller with the hydraulic properties of the system it serves, and the system providing the heat;
- the effect of different condenser water temperatures;
- start-up and shut-down under different conditions.

It is helpful if these method statements are signed-off by and presented to the client after each set of tests.

Performance Testing

Testing the plant to prove that it will meet its specified output is an obvious requirement. However, rigorous performance testing of any refrigeration system is difficult, time consuming and adds considerably to the cost of the installation. This is because:

- The refrigeration unit is always specified for a particular set of operating conditions (load, ambient temperature, etc.), yet these occur only rarely. This means that any tests will have to be adjusted to the design conditions by calculation. These calculations are complex because a change in one part of the plant will affect the readings elsewhere. Inevitably, this leads to some inaccuracy and to loss of confidence in the result.
- Normal field instrumentation does not need to be very accurate - very often repeatability is more important than accuracy. However, performance tests, particularly if they are related to payment, require a high level of accuracy to avoid unacceptable inaccuracies in the result. This inevitably raises instrumentation costs.
- For a test to be meaningful, it must be witnessed by the client or his representative and by an experienced representative from the supplier and/or installer. Again, this raises costs.

Taken together, these factors mean that rigorous performance tests are rarely performed on conventional refrigeration plants and chillers. However, with the less familiar absorption cooling system, it is reasonable that a purchaser might wish for greater reassurance than otherwise.

A compromise is available, in which the plant is proven in two stages. Firstly, the plant would require a few, low-cost, clearly labelled instruments to show key measurements on the plant, including flowrates, temperatures and pressures (the precise nature of these will vary from installation to installation). Most of these would

be part of the standard packaged equipment. The final stages of commissioning would include examination and recording of these readings. These can be compared with the design data to ensure that they are within the expected range. A successful result would allow provisional acceptance of the unit.

The second stage is long-term observation of the plant. The meaning of long-term will vary according to when the plant is commissioned, since this period should include some hot weather. During this period, further readings are taken, periodically, to ensure that performance is maintained within an expected range. At the expiry of this period with satisfactory performance, the purchaser (or his representative) and supplier/contractor meet or otherwise agree final acceptance.

It should be possible to agree, within the contract terms, a cash retention that would be released at final acceptance.

Maintenance

As for most refrigeration equipment, special skills are required for anything beyond routine maintenance of an absorption cooling plant. Details of the requirements are discussed in Section 6 Maintenance and Reliability.

The Royal Free Hospital made sure that its maintenance staff received adequate training so that they could carry out routine service work. The routine work is supported by a three-monthly maintenance visit by the suppliers.

Maintenance is usually arranged though a maintenance contract, often with the original supplier of the equipment - this is particularly sensible during the long-term observation of the plant. If this is intended, it is advisable to include at least the first year of such a contract within the project specification, so that the costs are known, and so that these costs are subject to competitive tender, in the same way as the main plant.

GLOSSARY

Technical Terms

Absorption cooling	A heat driven refrigeration cycle, based on absorption of refrigerant vapour into an absorbing fluid.
Air-conditioning	The process of modifying/controlling the temperature and humidity of air. It usually refers to situations where air needs to be cooled (and/or moisture removed).
Ambient (wet or dry bulb) temperature	The temperature of the outdoor environment. See wet and dry bulb temperatures defined below.
Baseload	The level of cooling load that will allow the plant serving the load to operate at or near full load for most of the time.
Brine	A general term for a mixture of water with a chemical salt, usually to depress the freezing point. The term is applied to secondary refrigerants (e.g. calcium chloride brine, which is a solution of calcium chloride and water), but is also applied to the lithium bromide solution in an absorption chiller.
Chiller	A word used to describe a refrigeration system where most of the components of the system are mounted on a single skid. In use, it normally refers to a system which cools water, but in this Guide, it is applicable to all absorption units. This is justified, as most absorption chillers cool water.
Chilled water	Refrigerated water, often used as a secondary refrigerant to transfer “cold” to end user processes.
Coefficient of Performance (COP)	The cooling produced by a refrigeration system divided by the energy supplied to it (in the same units, e.g. kW). For absorption cooling, the energy supplied is the heat supplied to the chiller. For conventional mechanical vapour compression cooling, the energy supplied is usually electricity only. COP is a key measure of refrigeration plant efficiency.
Coefficient of System Performance (COSP)	The ratio of the cooling capacity to the absorbed power of the whole refrigeration system. This measure includes the effect of the power consumption of auxiliary components such as fans and pumps, as well as the compressor. Thus, for an absorption chiller, electricity and heat are both included in the energy input.

Compressor	A mechanical machine that raises the pressure and temperature of a gas.
Condenser	A heat exchanger in which a vapour gives up heat and condenses.
Condensing temperature and condensing pressure	The temperature and pressure at which the refrigerant condenses.
Cooling duty	The instantaneous cooling output of a refrigeration system.
Cooling load/demand	The instantaneous cooling requirement served by a refrigeration system.
Cooling tower (open)	A device used to cool water through the process of evaporation. Water is sprayed into an air-stream, and some of it evaporates, cooling the remainder. The spray water is circulated to cool a remote source of heat (e.g. an absorption chiller). The wet bulb temperature controls performance, which is usually lower than the simultaneous dry-bulb temperature.
Cooling tower (indirect)	Similar in principle to an open cooling tower, but the water spray cascades over a heat exchanger containing the water (or other fluid) that is being cooled. This has the advantage that the water used in the spray is kept separate from the circulated water, and hence is a smaller quantity.
Dry (air) cooler	A heat exchanger, usually with fins attached to the tubes. The fluid in the tubes (usually water or and anti-freeze solution) is cooled by air, blown over the tube surface by a fan. The general construction is similar to that of a car radiator. The ambient dry-bulb temperature controls performance.
Dry bulb temperature	Temperature measured with a dry bulb thermometer. This measures the actual temperature of the air (see wet bulb thermometer below).
Evaporating temperature and evaporating pressure	The temperature and pressure at which a refrigerant evaporates.
Evaporator	A heat exchanger in which a liquid vaporises, producing cooling.
Heat exchanger	A device for transferring heat between two physically separate streams.
Heat pump	Any refrigeration system used for delivering useful heat. This is available from both the condenser and absorber in absorption systems, and the condenser of mechanical vapour compression systems. In the case of absorption chillers, the heat source provides the driving force, and the heat will be produced at an intermediate temperature. See the description in main text for more detail.
Heat recovery	Utilisation of waste heat from a process (usually to conserve energy).
Kelvin (K)	An absolute temperature scale where one degree is equal to one degree Centigrade (or Celsius). 0°C is equal to 273K.

Mechanical vapour compression cycle/ system/chiller	A type of refrigeration cycle which uses a compressor to remove low pressure vapour from an evaporator and deliver it to a condenser at a higher pressure. A brief description is included in *Technology basics* on page 4.
Monitoring (of plant)	The process of taking measurements of key operating parameters such as temperatures and pressures in order to appraise the operating state of a refrigeration system.
Packaged	A refrigeration plant of standard off-the-shelf design.
Part load operation	Operation of a refrigeration plant below the peak load capability.
Peak load	The maximum cooling load encountered in a particular refrigeration application.
Purging	Removal of air or non-condensable gases from an absorption chiller. Air can enter a lithium bromide/water absorption chiller because they normally operate under vacuum. A small amount of corrosion also occurs in lithium bromide/water absorption chillers, and the products of this include a small volume of gas, which must periodically be purged.
Primary refrigerant	The working fluid of a refrigeration system which absorbs heat in the evaporator and rejects heat in the condenser. In a lithium bromide/water chiller, the refrigerant is water, and in an ammonia/water system, the refrigerant is ammonia.
Secondary refrigerant	A fluid which is cooled in the evaporator by heat exchange with the primary refrigerant and then circulated to provide cooling of remote loads. For absorption chillers, this is normally water.
Specification	A formal statement of requirements for a proposed purchase.
Temperature amplifier	A configuration of the absorption cycle where heat is applied at one temperature and is boosted to a higher temperature. See the description in main text for more detail.
TEWI	Total equivalent warming impact. The TEWI represents the sum of the direct global warming caused by leakage of a refrigerant and the indirect global warming caused by the release of carbon dioxide from the combustion of fossil fuels.
Vapour compression cycle/system/chiller	A type of refrigeration cycle using a compressor to remove low pressure vapour from an evaporator and deliver it to a condenser at a higher pressure.
Variable Speed Drive (VSD)	An electronic device used to vary the speed of an electric motor.
Water chiller	A refrigeration system used to produce chilled water.
Wet bulb temperature	Temperature measured with a wet bulb thermometer. Because the bulb is covered in a film of water, evaporation causes a lowering of the measured temperature if the humidity is below 100%. Hence, the wet bulb temperature can be used in conjunction with the dry bulb temperature to measure relative humidity.

Financial Terms

Capital expenditure/investment	Expenditure on fixed assets (i.e. to purchase equipment).
Discounted Cash Flow (DCF)	A method of financial appraisal that takes account of the timing of the financial benefits derived from an investment. It is used as part of the calculation of NPV and IRR.
Discounting	A financial calculation that has the effect of converting sums of money received at some future date to their current equivalent value. The calculation is concerned only with the interest that can be earned over time on money available today and takes no account of inflation.
Financial appraisal	An assessment of the financial consequences of a proposal for capital expenditure.
Internal Rate of Return (IRR)	The rate at which the discounted values of the cash inflows is the same as that of the cash outflows. A method of financial appraisal that takes account of the timing of the financial benefits derived from an investment. See *Discount Factors, NPV and IRR* on page 32 for more detail.
Net Present Value (NPV)	A financial appraisal method involving the use of discount factors to convert the future cash flows resulting from an investment to a common base, i.e. the value now or present value. The present value of the cash outflows are set against the present value of the cash inflows to find the NPV. A positive NPV means that the investment meets the financial target set by the company. See *Discount Factors, NPV and IRR* on page 32 for more detail.
Payback period	The time it is estimated will be required for the additional profits stemming from a capital investment to equal the sum invested.
Present Value (Discount) Factor	A factor used to convert future cash flows to their equivalent value now at a given rate of interest.
Sensitivity checks	Testing the validity of financial appraisals by modifying the assumptions originally made to determine the impact on the financial outcome.

B

BIBLIOGRAPHY

More About Absorption Cooling

Application guide for absorption cooling/refrigeration using recovered heat - available from ASHRAE - see *Useful Contacts - Institutions* in Appendix C.

ASHRAE handbooks (the volumes Fundamentals and Refrigeration, all have sections on absorption cooling) - available from ASHRAE and CIBSE - see *Useful Contacts - Institutions*.

Annex 24: Absorption machines for heating and cooling in future energy systems, organised by the International Energy Agency - Heat Pump Programme - is a forum for information on the development of the absorption technology, and includes a series of newsletters relating to the UK. The Website is http://www.ket.kth.se/Avdelningar/ts/annex24/

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Guideline on methods of calculating TEWI (Total Equivalent Warming Impact) - published by the British Refrigeration Association (BRA) - see *Useful Contacts - Institutions*.

American Gas Cooling Centre: the Website, http://www.agcc.org/ has some useful further information on direct gas fired units, including .../BasicAbsorption.zip and .../AbsCaseStudy.zip which are downloadable files containing PowerPoint presentations.

Technical Papers Giving Additional Information on Absorption Cooling

General:

Theory and application of absorption refrigeration systems, by R. Tozer and R.W. James - Institute of Refrigeration paper, Thursday 28th September 1995, available from the Institute - see *Useful Contacts - Institutions*.

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Recognised Standards Applicable to Absorption Chillers

Requirements for gas fired absorption and adsorption heat pumps, AGA 10-90.

Absorption water-chilling and water heating packages, ARI 560-92.

Guidance on Handling of Inhibited Lithium Bromide Solutions

Absorption machine brines: Hazards and Risks in use; Leverton-Clarke Ltd. (Emergency assistance is also available on: daytime: 01256 810393 or after normal working hours: 01276 66321.)

Guidance on Government Regulations

Occupational exposure limits, associated with the COSHH Regulations: EH40 Occupational Exposure Limits (published annually by HSE Books).

Pressure Systems and Transportable Gas Containers Regulations (explanatory documents): Approved Code of Practice - Safety of Pressure Systems - first published 1990 as COP 37.

Health & Safety Commission guidance note - Guidance on Regulations - first published 1990 as HS(R)30.

Construction (Design and Management) Regulations 1994 (CDM Regulations), available from local HSE area offices:

HSE Information Sheets, Nos. 40, 41, 42, 43 and 44 explain, respectively, the roles of the planning supervisor, designer, the pre-tender and construction phase health and safety plans, and the health and safety file.

C

USEFUL CONTACTS

Suppliers

Apex Air Conditioning, Rhodyate House, Woodhill, Avon BS19 5AF, Tel: 01934 838 190, (Robur Ammonia units).

Arun Environmental, Fiscal House, 2 Havant Road, Emsworth, Hampshire PO10 7JE, Tel: 01243 372 232, (Robur Ammonia units).

Birdsall Services, Unit 6, Frogmore Rd, Hemel Hempstead, Herts HP3 9RW, Tel: 01442 212 501, (maintenance and commissioning services, plus supply of Robur Ammonia, Kawasaki & Thermax LiBr units).

Borsig GmbH, D-1000, Berlin, Germany (Industrial Ammonia units).

Carrier Air Conditioning, Airport Trading Estate, Biggin Hill, Kent TN16 3BW, Tel: 01959 571 211, Fax: 01959 571 009, (Carrier LiBr units).

Climate Equipment Ltd, Highlands Road, Shirley, Solihull, West Midlands B90 4NL, Tel: 0121 705 7641, Fax 0121 704 1371, (Thermax LiBr units).

Colibri bv, Tentstraat 5-A, 6291 bc Vaals, Netherlands, Tel: 31 43 30 66 227, Fax: 31 43 30 65 797, E-mail: colibri@arena.de, (Colibri Industrial Ammonia units).

Gas Force, 39 Ilford Hill, Ilford, Essex IG1 2AJ, Tel/Fax: 01243 372 232, (Robur Ammonia units).

McQuay International, Bassington Lane, Cramlington, Northumberland NE23 8AF, Tel: 0191 201 0412, Fax: 01670 714 370, (Sanyo LiBr units).

Stork Ketels bv, PO Box 20, 7550 GB Hengelo, Netherlands, Tel: 31 74 240 1762, Fax: 31 74 242 4790, (Stork Industrial Ammonia units).

Thermax Europe Ltd., 94 Alston Drive, Bradwell Abbey, Milton Keynes MK13 9HF, Tel: 01908 316 216, Fax: 01908 316 217, (Thermax LiBr units).

Trane UK Ltd, Northern Cross, Basing View, Basingstoke RG21 4HH, Tel: 01256 306030, Fax: 1256 306031, (Trane LiBr units).

Weir Westgarth, 149 Newlands Road, Cathcart, Glasgow G44 4EX, Tel: 0141 633 1336, Fax: 0141 633 3289.

York International Ltd, Gardiners Lane South, Basildon, Essex SS14 3HE, Tel: 01268 28 7676, Fax: 01268 28 1765, (York LiBr units).

Institutions

ASHRAE: American Society of Heating, Refrigerating and Air-conditioning Engineers, Atlanta, GA, USA, Website: http://xp10.ashrae.org/bookshop.htm

BRA: British Refrigeration Association, FETA, Henley Road, Medmenham, Marlow, Bucks SL4 2ER, Tel: 01491 578674, E-mail: info@feta.co.uk, Website: http://www.feta.c.uk/bra.html

CHPA: Combined Heat and Power Association, Grosvenor Gardens House, 35/37 Grosvenor Gardens, London, SW1W 0BS, Tel: 0171 828 4077, Fax: 0171 828 0310, E-mail: info@chpa.co.uk

CIBSE: Chartered Institution of Building Services Engineers, 222 Balham High Road, London SW12 9BS, Tel: 0181 675 5211.

Institute of Refrigeration: Kelvin House, 76 Mill Lane, Carshalton, Surrey, SM5 2JR, Tel: 0181 647 7033, Fax: 0181 773 0165, E-mail: instor@ibm.net, Website: http://www.ior.org.uk

The Heat Pump Centre: (the HPC is the IEA Information Centre for the IEA Heat Pump Programme, which also works on absorption cooling) IEA Heat Pump Centre, PO Box 17, 61300 AA, Sittard, Holland, Fax: +31 46 4510389, Website: http://www.heatpumpcentre.org

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

For buildings-related publications please contact:
Enquiries Bureau
BRECSU
Building Research Establishment
Garston, Watford, WD2 7JR
Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

For industrial and transport publications please contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Didcot, Oxfordshire,
OX11 0RA
Fax 01235 433066
Helpline Tel 0800 585794
Helpline E-mail etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.